









TOTAL E&P PNG LIMITED

PAPUA LNG

Upstream Environmental Impact Statement

Volume 2: Environmental and Social Baseline

Part 2
Upstream Hydrology and Meteorology Baseline Report

TOTAL
TOTAL E&P PNG LIMITED

BMT WBM

"Where will our knowledge take you?"



Papua LNG Project

Upstream Hydrology and Meteorology Baseline Report

August 2017

Prepared for Total Exploration and Production PNG Limited

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Papua LNG Project - Upstream Hydrology and Meteorology Baseline Report

Prepared for Total E&P PNG Limited

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BMT WBM Pty Ltd
Level 8, 200 Creek Street
Brisbane Qld 4000
Australia
PO Box 203, Spring Hill 4004

Tel: +61 7 3831 6744
Fax: + 61 7 3832 3627

ABN 54 010 830 421

www.bmtwbm.com.au

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Project Manager:	Jeremy Visser
Author:	Eoghain O'Hanlon, Luke Kidd, Jessie Hayne, Jeremy Visser
Client:	ERIAS Group Total E&P PNG Limited
Client Contact:	Clark Monahan
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Synopsis: **ESBS Technical Report prepared by BMT WBM for Papua LNG EIS/ESHIA for the following components: Upstream Hydrology and Meteorology**

TECHNICAL REPORTS SERIES

Report Number	Description
0	***Papua LNG ESBS – Upstream Hydrology & Meteorology***

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Executive Summary

Background

Total E&P PNG Limited (TEP PNG), a wholly owned subsidiary of TOTAL S.A. (TOTAL), is the largest partner in a joint venture to develop the Elk-Antelope gas field, located in Petroleum Retention License 15 (PRL-15) in Gulf Province, Papua New Guinea. This Project, known as the Papua LNG Project, will comprise upstream production well development and associated infrastructure at the gas field within PRL-15, construction of an upstream central processing facility (CPF) and delivery of gas and condensate via onshore and offshore export pipelines to a liquefied natural gas (LNG) plant site at Caution Bay, Central Province, 20 km northwest of Port Moresby.

This technical report provides the findings of a baseline study in relation to hydrology and meteorology (including sediment transport) in the study area. This technical report forms part of the Environmental and Social Baseline Study (ESBS) for the Project Environmental Impact Statement/Environmental, Social and Health Impact Assessment (EIS/ESHIA) which is being managed by ERIAS Group. The study area encompasses three catchments, namely (1) lower Purari River catchment (downstream of Hathor Gorge), (2) upper tributaries of the Pie River catchment, and (3) upper tributaries of the Era River catchment.

The key objectives of the ESBS for hydrology and meteorology are to:

- Identify the national, international and corporate regulatory and policy framework for assessment of impacts to hydrology and meteorology (including flooding and sediment loads), including the technical elements required to conduct an EIS/ESHIA.
- On the basis of a review of previous studies, provide a high-level baseline description of hydrological, meteorological and sediment transport processes within the study area.
- Develop and implement numerical models to simulate baseline flow processes and catchment sediment loads in the study area catchments.

Study Approach

Existing information was reviewed to characterize baseline hydrology and meteorology in the study area, and to identify key information gaps requiring further assessment. Key information sources and gaps identified were as follows:

- Purari River – There is existing information on rainfall, flow regimes, geomorphological and sediment transport processes in the catchment, most of which was derived from studies for a hydropower project at Wabo. These studies generated both a flow duration curve and sediment rating curve, and while useful background material, were not sufficient for the purposes of the Project EIS/ESHIA. Historical rainfall and stream gauge data are also available in the catchment.
- Pie and Era rivers – Limited baseline hydrology and meteorology information on local waterways, based on local scale assessments of upper tributaries coinciding with sampling sites for the Elk/Antelope Gas Field Project (GHD, 2015a, 2015b, 2015c and 2015d).

In order to supplement gaps and consistent with good international industry practice (GIIP), modeling of hydrological, hydraulic and sediment transport processes was undertaken for catchments in the study area. This consisted of:

(1) Hydrology model and rainfall frequency analysis for representative parts of the Purari, Era and Pie river catchments, utilizing a Unified River Basin Simulator (URBS) hydrologic model and the methodology prescribed in the Papua New Guinea Flood Estimation Manual (FEM – SMEC, 1990). The URBS model indicates the likely flows associated with particular magnitude rainfall events.

(2) Hydraulic (TUFLOW) models for relevant sub-catchments associated with likely infrastructure locations. The models indicate the likely flooding extents associated with predicted flows generated by the hydrology model within the modeled extent.

(3) Catchment model for the Purari River catchment, utilizing a Source Catchments model. This model estimates sediment loads generated by catchment runoff.

Assessments were also undertaken of climate (e.g. temperature, wind, rainfall, evaporation) and bathymetry, based on both existing literature and meteorological modeling undertaken by BMT ARGOSS.

Study Findings

The key findings of this baseline assessment are as follows.

Bathymetry

- The Purari River is a large meandering river for most of its length within the study area. As a result, it is characterized by scour and deep channels on the outside of bends and a shallow, depositional environment on the inside of bends. The morphology of the river is also highly variable.
- As a result of scour, a semi-continuous channel of up to 7 m depth extends from the mouth of the river (inside the bar) to Herd Base in normal conditions.
- Cross-sections of the river bed vary based on location and the influence of tributary streams. One cross-section upstream of Herd Base (and Kuku Creek) has a U-shaped bed while a nearby section, downstream of Herd Base and Kuku Creek, featured a significant in-stream bank caused by sediment deposition from Kuku Creek, with deep scour on the opposite side of the creek.
- The Purari River mouth features a large shallow bar, caused by coastal processes in this area.

Climate

- Papua New Guinea is located within the equatorial humid tropics and except for the highlands, experiences hot and humid conditions year-round. Papua New Guinea is located on the eastern edge of the Asian monsoon area where the Pacific Inter Tropical Convergence Zone (ITCZ) widens into the broad maritime continent doldrums area.
- The two seasons of the study area are the northwest monsoon (December to March) and the southeast trade winds seasons (May to October). These are dominated by changes in the ITCZ position causing changes in wind direction.

- Wind roses for PRL-15 produced from meteorological modeling suggest little change between seasons in the dominant wind directions. This may be a result of a low-level convergence (i.e. zone where two prevailing flows meet and interact) over PRL-15.
- Winds along the coastline are much higher and more closely linked to changes in season than further inland.
- A temperature-elevation relationship is noted in the Purari River catchment, with areas at lower elevation having higher temperature ranges than at higher elevations in the catchment. However, along the coast, sea breezes cause a reduction in the maximum temperature in this area.
- Temperature does not vary significantly between months, with more change expected to occur across years.
- The south-easterly trade winds predominate from May to October. During this season, very heavy rainfall occurs in the Purari River catchment downstream of Hathor Gorge, primarily as a result of a low level convergence. This contrasts with rainfall in upper parts of the catchment (including the Aure River catchment) where rainfall is highest during the northwest monsoon (December to March).
- Significantly higher annual rainfall occurs downstream of Hathor Gorge than in the upper part of the Purari River catchment.
- Year-to-year variability in rainfall is high in Papua New Guinea, with the wettest years receiving up to three times the rainfall of the driest years (ABM/CSIRO, 2011).
- The El Niño-Southern Oscillation (ENSO) drives much of this variability. Generally, El Niño years are drier than average while La Niña years are wetter than average. Another impact of El Niño is a late start to the monsoon season. As there is no consistency in projections of future ENSO activity, it is not possible to determine whether inter-annual variability in rainfall will change in the future (ABM/CSIRO, 2011).

Hydrology

- The Purari River catchment is the main catchment (26,300 km^2 at Wabo) within the study area. The Aure River (contributing catchment area 4,355 km^2) is the main tributary of the Purari River downstream of Wabo that is relevant to the Project. The headwaters of Pie and Era rivers also occur within the study area. A total of 80 sub-catchments have been identified in the Purari, Pie and Era river catchments. Contribution of streamflow from sub-catchments in PRL-15 to the Purari River are negligible in comparison to contributions of the Aure River, based on comparisons between modeled upstream and downstream streamflows.
- The Purari River is capable of rapid changes in water level associated with changing flow events. This is indicated by river level gauging undertaken at Herd Base.
- Pickup and Chewings (1983) indicate mean daily discharge from the Purari River to be 2,360 m^3/s, with a maximum up to 10,405 m^3/s and an average minimum of 1,920 m^3/s. The Aure River mean daily discharge is 307 m^3/s.
- The contribution of waterways within PRL-15 to the streamflow in the Purari River is considered to be negligible by comparison to the flow contribution of the Aure River.

- No information is available regarding flooding and flow regimes in the Pie and Era river catchments, but it is expected to strongly correlate with patterns in the Purari River in the area of PRL-15.
- There is low inter-annual (i.e. between years) variability in flow regimes (including flooding) and rainfall.

Hydraulics

- The Purari River is capable of rapid changes in water level (in order of meters) associated with changing flow events. This is indicated by river level gauging undertaken at Herd Base.
- Flood events and low flow events within the study area can occur throughout the year but the largest tend to occur in association with seasonal rainfall patterns. Due to the difference in rainfall patterns at PRL-15 comparative to the upper Purari River catchment, both flooding and low flow events can occur in the southeast trade winds season (in particular during June to September). This is the result of high rainfall occurring at this time in PRL-15 (causing flood events) but low rainfall in the upper catchment (causing low volumes flowing into the river in the vicinity of PRL-15).
- The Aure River, by contrast, tends to flood during the north-westerly season (February to March) when rainfall is high, and has low flows in the south-easterly season. No information is available regarding flooding and low flow events in the Pie and Era river catchments but this is expected to strongly correlate to the Purari River downstream of Hathor Gorge.
- Variability from year to year in the nature of flooding and low flow events across years is relatively low.
- The sub-catchments of interest in the study area can generally be grouped into two main types of channel/floodplain. These are well-defined channels, marked by flooding constrained to a single channel, and multi-channel floodplains where flood events spread over a large area. Well-defined channels are more common in the upper tributaries of the Era River and the tributaries of the Purari River in PRL-15, while multi-channel floodplains are more common in the tributaries flowing to the Purari River delta.
- Of these two channel types, flood velocities and depths, are highest and flood extents lowest in the well-defined channels, and the reverse for multi-channel floodplains. The flood extent and height across different average recurrence interval (ARI) events for well-defined channels does not change significantly due to the containment of flood water within the stream channels.
- Flood velocity and depth does not change significantly between the 10, 50 and 100 year ARI events, particularly when comparing the 50 and 100 year events.
- Simulations of flooding at the PRL-15 oxbow wetlands, Oyomo Creek and Herd Base peak flooding heights of less than 3.0 m and all three locations with low velocities. Flooding at Herd Base is associated with back flow from Kuku Creek and is confined to areas immediately adjoining the creek. Oyomo Creek has a similar flooding pattern but with a larger extent. Flooding at the PRL-15 oxbow wetlands is very widespread and deepest in the area formed between the tie channels, oxbow lake and Purari River.
- The PRL-15 oxbow wetlands are expected to be inundated by water from the Purari River on an annual basis.
- The sub-catchments of interest in the study area can generally be grouped into two main channel types from a flooding perspective. These are: (i) well-defined channels, marked by flooding constrained to a single channel, and (ii) multi-channel floodplains, where flood events spread over a wide floodplain area.

Well-defined channels are more common in the upper tributaries of the Era River and the tributaries of the Purari River within PRL-15, while multi-channel floodplains are more common in the tributaries flowing to the Purari River delta downstream of PRL-15.

- Of these two channel types, flood velocities are highest (up to 7.8 m/s), flood depths greatest and flood extents smallest in the well-defined channels, and the reverse for multi-channel floodplains. The flood extent and depth across different ARI events for well-defined channels does not change significantly due to the containment of flood water within the stream channels.
- Stream velocity does not change significantly between the 10, 50 and 100 year ARI events, particularly when comparing the 50 and 100 year events.
- Simulations of flooding at the PRL-15 oxbow wetlands, Oyomo Creek and Herd Base peak flooding heights of less than 3.0 m and all three locations with low velocities. Flooding at Herd Base is associated with back flow from Kuku Creek and is confined to areas immediately adjoining the creek. Oyomo Creek has a similar flooding pattern but with a larger extent. Flooding at the PRL-15 oxbow wetlands is very widespread and deepest in the area formed between the tie channels, oxbow lake and Purari River.
- The PRL-15 oxbow wetlands are expected to be inundated by water from the Purari River on an annual basis.

Catchment Sediment Loads

- Catchment sediment loads within the Purari River are predominantly comprised of silts and clays, with a significant contribution of clays derived from the Aure River. In total, the Aure River is expected to contribute 55% of the sediment loads in the Purari River at the confluence of the two rivers, with only smaller amounts of sediment likely to be derived further downstream.
- Sediment loading contributions to the Purari River from PRL-15 sub-catchments are negligible between locations upstream and downstream of PRL-15, with most sediment inputs along this reach coming from the Aure River.
- There is a high relationship between rainfall and runoff in the area of PRL-15, suggesting sediment transport is highest during the southeast trade wind season (May to October for Purari, Pie and Era river catchments and the northwest monsoon season (February to March) for Aure River catchment).

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1 Introduction

1.1 Project Overview

Joint venture partners, Total E&P PNG Limited (TEP PNG) (40.13%), ExxonMobil (37.03% - through SPI (208) Limited (35.48%) and SPI Security Holdings Limited (4.55%)) and Oil Search Limited (22.84 % - though Pac LNG Assets Limited (6.75 %), Pac LNG International Limited (5.10%), Pac Overseas Limited (5%), Pac LNG Holdings Limited (3.49%) and Pac LNG Investments Limited (2.50%)) are planning the development of the Elk-Antelope gas fields located in Gulf Province, Papua New Guinea. The gas fields are located within Petroleum Retention License 15 (PRL-15). The Project will include infrastructure development inside PRL-15, and the construction of gas and condensate pipelines (export pipeline) to a liquefied natural gas (LNG) plant site at Caution Bay, 20 km northwest of Port Moresby.

The Project area comprises the physical footprint of the various Project components and associated infrastructure as detailed below (Figure 1-1).

- Production, processing and related facilities (within PRL-15):
  - Wellpads and the associated gathering system (including flowlines and trunkline).
  - Central processing facility (CPF).
  - Logistics base and river offloading facilities, accommodation camps, airstrip, roads and bridges.
  - Quarries and communications infrastructure.
  - Initial section of the onshore export pipeline.
- Onshore pipeline (outside PRL-15):
  - Remainder of the onshore export pipeline to landfall on the gulf coast including valve stations.
  - Temporary laydown areas and camps.
  - Quarries, communications infrastructure.
- Transport (river) corridors:
  - River transport routes— the Purari, Urika-Ivo and Wame-Varoi rivers.
- Offshore pipeline:
  - Offshore section of the export pipeline to a LNG Plant site at Caution Bay.

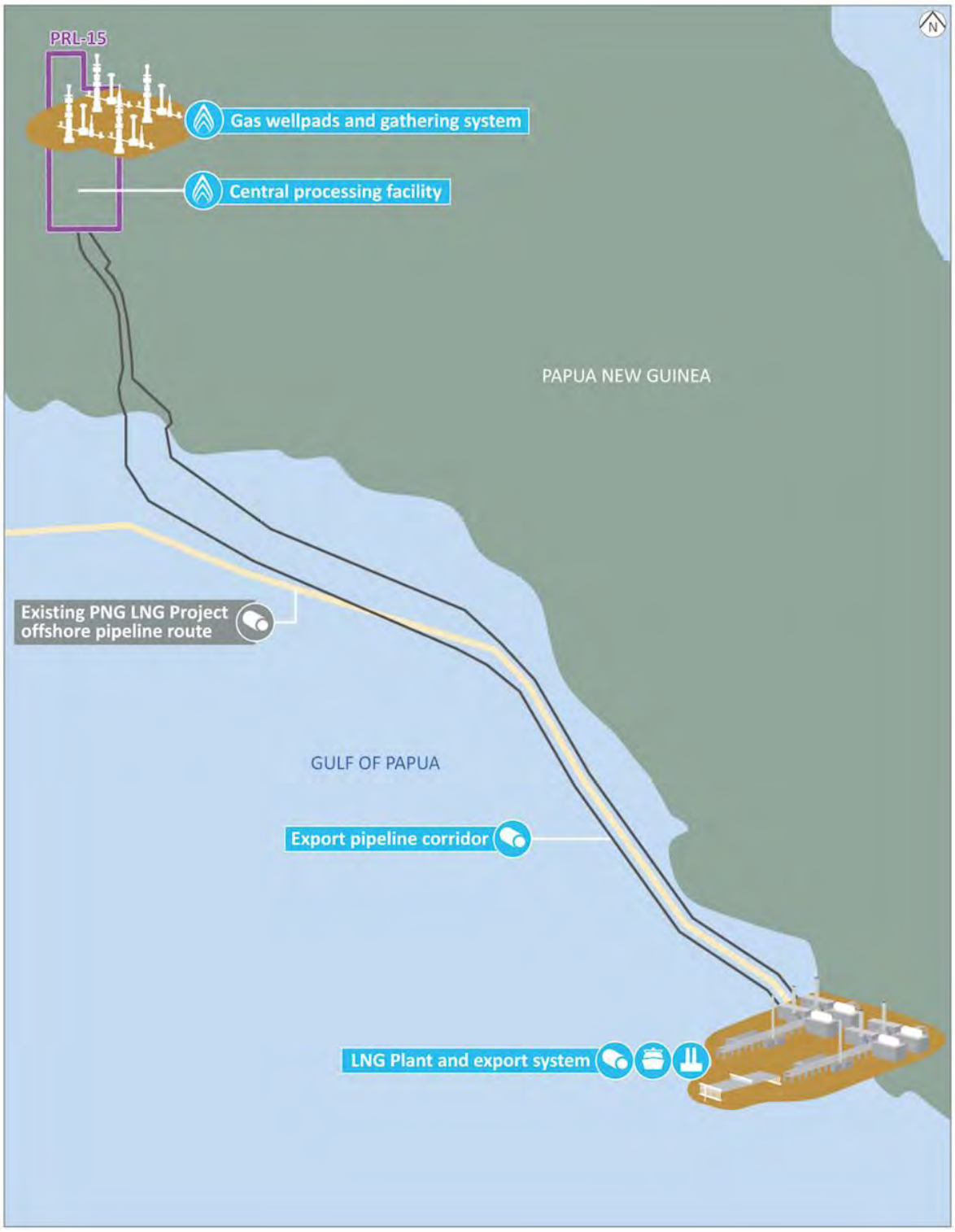


Figure 1-1 Schematic of the Project

1.2 Study and Objectives

This technical report describes the baseline hydrology and meteorology of the study area. This report is part of the Upstream Hydrology and Meteorology Study for the Environmental Impact Statement and the Environmental, Social and Health Impact Assessment (EIS/ESHIA) for the Project. In particular, his report forms part of the Environmental and Social Baseline Study (ESBS) component of the EIS/ESHIA.

The study objectives of the Upstream Hydrology and Meteorology Study are to:

- Describe the hydrology and sedimentology of surface water bodies and climatic conditions of the Project area to provide a description of existing conditions for the EIS/ESHIA.
- Provide information to assess the risk of flooding and scouring along the proposed pipeline alignment and sediment transport impacts downstream of disturbance areas.
- Support the assessment of Project-related impacts on surface water hydrology and sedimentology, water quality, aquatic ecology and resource uses (ecosystem services).

Within the context of these study objectives, this ESBS technical report achieves the following:

- Identifies the national, international and corporate regulatory and policy framework for assessment of impacts to hydrology and meteorology (including flooding and sediment loads), including the technical elements required to conduct an EIS/ESHIA.
- On the basis of a review of previous studies, provides a high-level baseline description of hydrological, meteorological and sediment transport processes within the study area.
- Develops and implements numerical models to simulate baseline flow processes and catchment sediment loads in the study area catchments.

2 Regulatory Framework and Standards

The Project is regulated primarily under the *Environment Act 2000* and the *Oil and Gas Act 1998*. In addition, TEP PNG will be guided by company environmental performance specifications and international guidelines for the purposes of the EIS/ESHIA. Therefore, there are three sets of performance standards/guidelines applicable to the EIS/ESHIA:

- Papua New Guinea Legislation, including Conservation and Environmental Protection Authority (CEPA) operational procedures and codes of practice under the *Environment Act 2000*.
- International environmental and social guidelines, including the International Finance Corporation (IFC) Performance Standards on Environmental and Social Sustainability.
- TOTAL company standards and commitments.

2.1 Papua New Guinean Authorities and Legislation

The following Papua New Guinean legislation is considered relevant for the purposes of the Project EIS/ESHIA:

- *Environment Act 2000*, including regulations and operational procedures/information guidelines.
- *Oil and Gas Act 1998*.

These instruments identify critical aspects of the EIS process.

An EIS in Papua New Guinea is required under the *Environment Act 2000* in order to assess and understand the potential environmental impacts of significant activities prior to the issue of an Environment Permit. In particular, an EIS is required for Level 3 Activities identified under the Environment (Prescribed Activities) Regulation 2002. The Project is a Level 3 Activity in accordance with Sub-Category 18 of the Regulation. The *Environment Act 2000* and EIS process is administered by CEPA.

Under the *Oil and Gas Act 1998* the issue of licenses for petroleum projects, including Petroleum Development Licenses (PDLs), Pipeline Licenses (PLs) and Petroleum Processing Facility Licenses (PPFLs) require consideration of environmental aspects and management actions. A PDL can only be issued where the Minister administering the Act is satisfied that the project provides for the protection of the environment and welfare of people in the project area. In practice, the Minister relies on the EIS developed under the *Environment Act 2000* in making this assessment. The Minister administering the Act is the Minister of Department of Petroleum and Energy.

In preparing an EIS and applying for an Environment Permit, a proponent is required to following the process set out in operational procedures and guidelines prepared by CEPA. These include the following:

- Operational Procedure (2013): *Information Requirements for Permit Application & Registration of Intention to Carry Out Preparatory Works*.
- Information Guideline GL-ENV/02/2004: *Guideline for Conduct of Environmental Impact Assessment & Preparation of Environmental Impact Statement*.

- Information Guideline GL-ENV/03/2004: *Guideline for Submission of an Application for an Environment Permit to Discharge Waste.*
- Technical Guideline IB-ENV/04/2004: *Water & Land Discharges*.

2.2 International Standards and Guidelines

TEP PNG has committed to preparing an EIS/ESHIA for the Project consistent with a number of international standards and guidelines. These are:

- Equator Principles and World Bank Safeguards.
- IFC Performance Standards.
- Organization for Economic Cooperation and Development (OECD) Common Approaches.
- International Petroleum Industry Environmental Conservation Association (IPIECA) Guidelines.
- Any international convention ratified by the Government of Papua New Guinea (that has not been given effect under legislation listed above).

Preparation of an ESHIA for the purposes of environmental due diligence is required under the World Bank Safeguards, Equator Principles and OECD Common Approaches. The IFC Performance Standards provide specific guidance on the ESHIA process.

IFC Performance Standard (PS) 1 establishes the framework for preparing an ESHIA in order to assess and manage the impacts from a particular activity. The remaining Performance Standards (PS2 to PS8) provide more detail on the assessment and management of impacts in particular areas, including pollution/discharges to the environment (PS3) and biodiversity conservation (PS6). The IFC Performance Standards are supplemented by Environmental, Health and Safety (EHS) guidelines which provide examples of good international industry practice (GIIP) for certain activities.

In accordance with the IFC Performance Standards an ESHIA is required to consider the risk of an activity to the environment within the activity's 'area of influence'. This includes consideration of the impacting processes in the relevant industry-specific EHS Guidelines.

In accordance with the IFC Performance Standards an ESHIA is required to consider the risk of an activity to the environment within the activity's 'area of influence'. This includes consideration of the impacting processes in the relevant industry-specific EHS Guidelines. These include EHS Guidelines for LNG Facilities, Onshore Oil and Gas Development and Crude Oil and Petroleum Terminals.

Under Performance Standard 3 the ESHIA is required to describe the ambient environment conditions in the area of influence, including the assimilative capacity. This then forms the basis of assessing potential pollution impacts and for the setting of impact criteria. Performance Standard 6 requires the ESHIA to include a distinction between 'modified', 'natural' and 'critical' habitat in order to appropriately quantify and manage impacts to biodiversity and ecosystems services.

The IPIECA has prepared a number of guidelines for the petroleum industry to advise proponents on best practice related to ESHIA processes. These guidelines include a focus on biodiversity and ecosystem services, oil spill preparedness, and water.

The key features of the most relevant guidelines include: locating and assessing sensitive areas (including protected areas, sensitive habitats and rate, threatened or endangered species) as part of project planning; assessing baseline ecological conditions to inform the occurrence of and vulnerability to alien invasive species; and assessing the potential impacts of abstraction of and discharge to naturally-occurring water sources, including cumulative impacts and the effects of climate change.

2.3 TOTAL Company Standards and Commitments

TOTAL has developed the following general specifications for the purpose of environmental impact assessment that are relevant to the Project EIS/ESHIA:

- GS EP ENV 120: Environmental impact assessment of E&P activities.
- GS EP ENV 111: Environmental Baseline and Monitoring Studies: Onshore Sites.
- GS EP ENV 112: Environmental Baseline and Monitoring Studies: Offshore Sites.

GS EP ENV 120 provides details on the process for undertaking an environmental impact assessment and preparing an environmental management plan. The instrument adopts the ISO14001 approach for impact assessment and management. Some relevant specific requirements of the specification include:

- Identification of the physical, biological and socio-economic context of a project, including sensitivities of the environment.
- Assessment of impacts within an ‘area of influence’.
- Use of a modeling study (if relevant) to assess liquid effluent discharges dispersion.

The specifications also identify a methodology for impact assessment and contents of an environmental management plan (including oil spill contingency plan).

GS EP ENV 111 and GS EP ENV 112 specify the type of data to be collected for baseline purposes. These include physical properties of in-stream sediment and surface water.

3 Study Area

3.1 Study Area

The Project occurs across the northern and eastern ends of the Gulf of Papua, as shown in Figure 1-1. Studies are being undertaken across much of this area as part of the EIS/ESHIA. For the purposes of this report, the study area only includes the upstream components associated with freshwater and estuarine waterways. While the study area includes all of the Purari River catchment, as well as the Pie and Era river catchments, the majority of the Project activities will occur downstream of Hathor Gorge. The wider study area is shown in Figure 3-1 with a more focused Project area downstream of Hathor Gorge shown in Figure 3-2. The topography of the study area is shown in Figure 3-3.

Downstream of Hathor Gorge, the most significant tributary to the Purari River is the Aure River, although other smaller tributaries also flow into the river. There are a number of interconnected wetlands within the Purari River floodplain. Smaller tributaries within PRL-15 include:

- Hou Creek – located in northern part of PRL-15, drains to Purari River.
- Boa Creek and Mena River – located in central part of PRL-15, drain to Era River.
- Kuku and Oyomo creeks – located in southern part of PRL-15, near Herd Base, drain to Purari River.

At the top of the delta, the Purari River splits into three channels: Purari River (eastern channel) and Urika-Ivo River (central channel), both of which flow directly into the Gulf of Papua; and Wame-Varoi River (western channel) which flows into Port Romilly. The Pie River also flows into Port Romilly. The Upstream Freshwater and Estuarine Biodiversity Baseline Report (BMT WBM, 2017b; Part 5 of ESBS Dossier) provides description of the different waterway types (e.g. high gradient tributary streams, turbid main river channels) that occur in the study area.

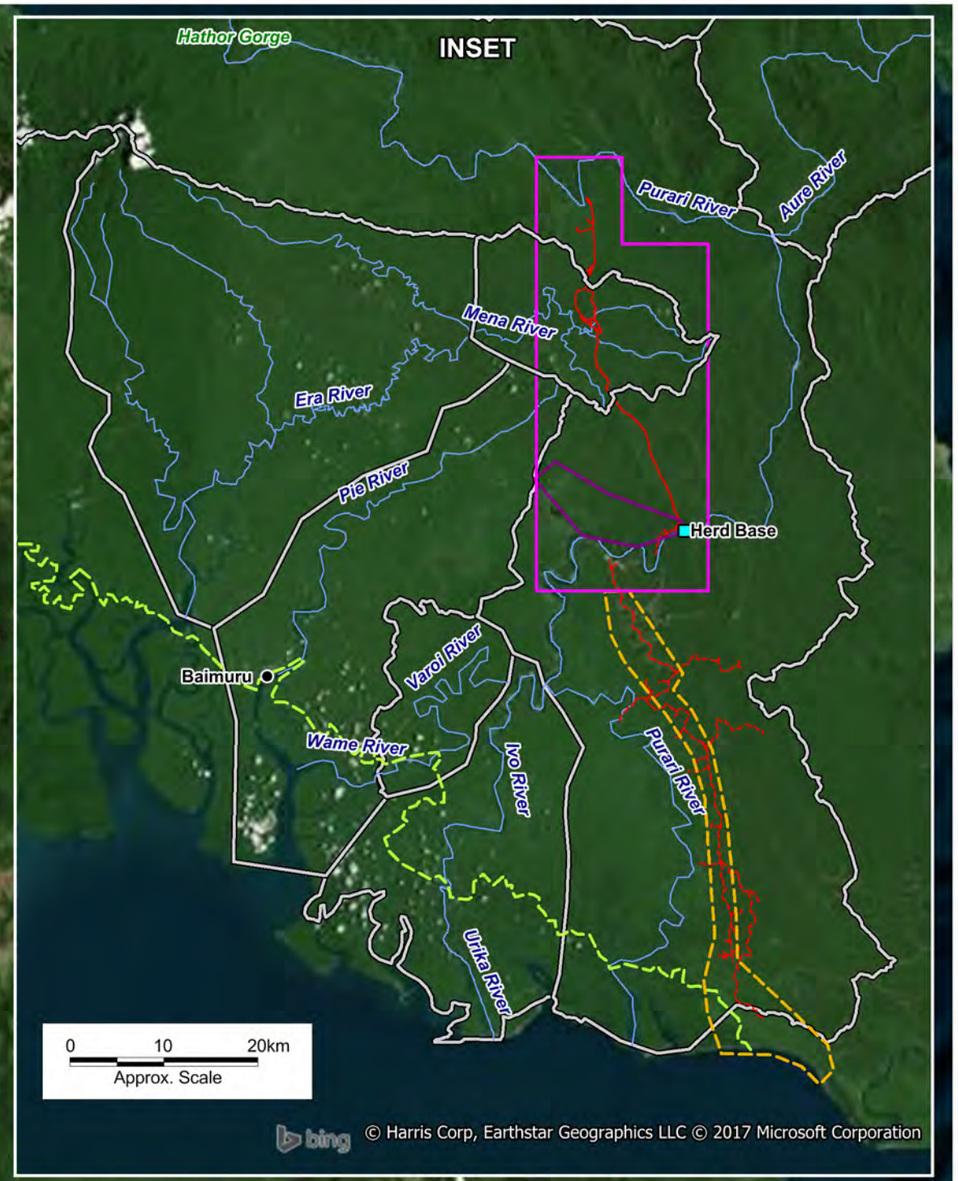
Figure 3-4 to Figure 3-7 show some of the waterways which occur within the study area.

3.2 Climate Setting

Papua New Guinea is located within the equatorial humid tropics and except for the highlands, experiences hot and humid conditions year round. Papua New Guinea is located on the eastern edge of the Asian monsoon area where the Pacific Inter Tropical Convergence Zone (ITCZ) widens into the broad maritime continent doldrums area (Hall, 1984).

The south-easterly trade winds predominate from May to October. During this season very heavy rainfall occurs on windward slopes of areas exposed to the southeast and southern face of the central cordillera. The belt of monsoonal westerly winds to the north of the ITCZ dominates from December to March (Bourke and Harwood, 2009). Highly localized heavy rainfall occurs in this season over most of Papua New Guinea except in the highlands. Between these two seasons, a transition period occurs (i.e. April and November) where neither wind direction dominates.





bing Image courtesy of NASA Earthstar Geographics SIO © 2017 Microsoft Corporation



LEGEND

- Study Area
- Catchment Boundaries
- Waterways
- PRL-15 boundary
- CPF area
- Herd Base
- Narrowed Onshore Pipeline Corridor
- Indicative Estuarine Boundary
- Existing Roads
- Existing Tracks

Title:

Upstream Hydrology and Meteorology Study Area

Figure: 3-1

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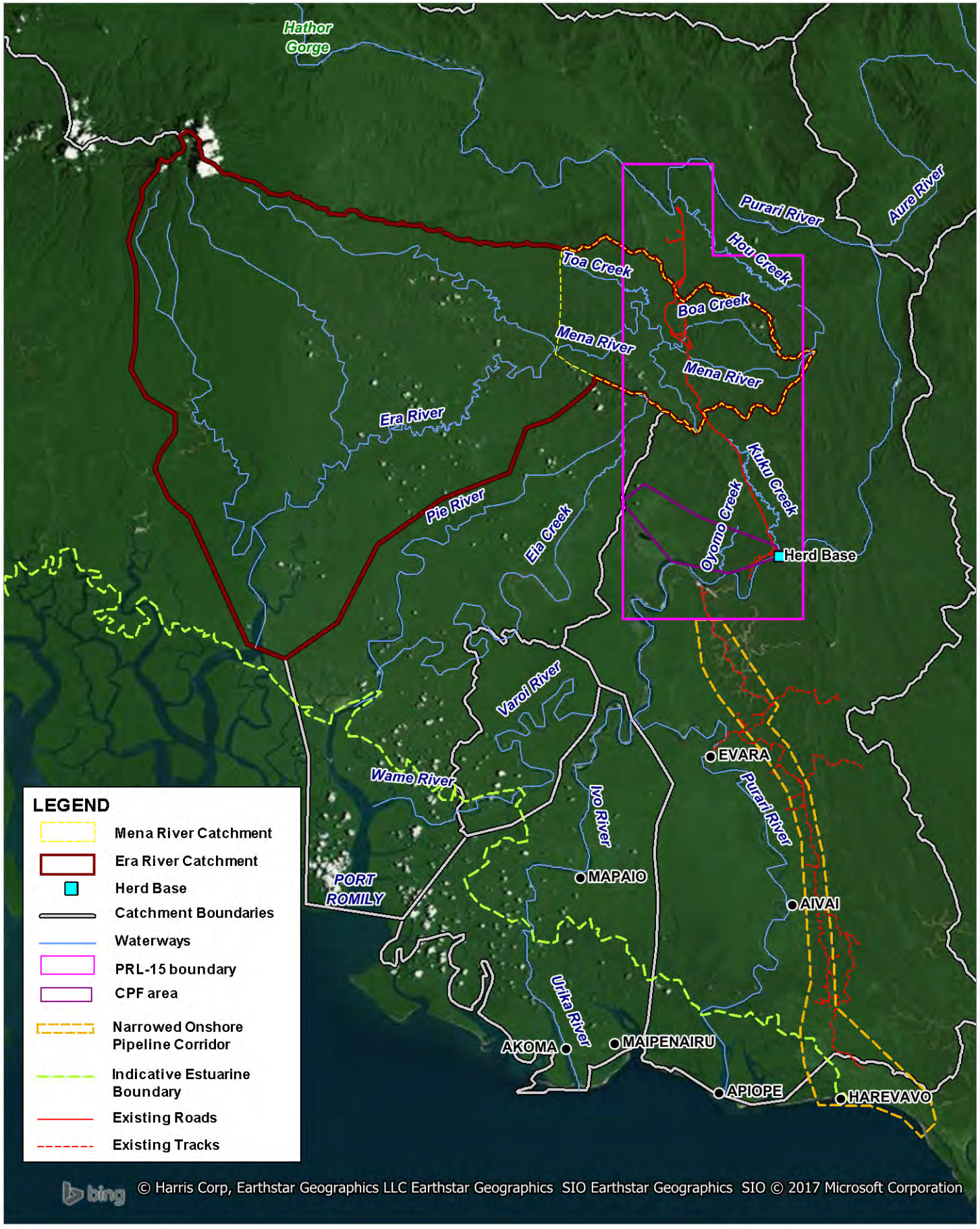
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Scale - Main Map

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Title:
Project Focus Area

Figure: 3-2

Rev: A

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Approx. Scale

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MOUNT HAGEN
KUNDIAWA
GOROKA
MENDI
LAE
KEREMA

LEGEND

PRL-15 Boundary

Study Area

Waterways

Town

-1000 -750 -500 -250 0 250 500 750 >1000

Elevation (m)

Title:

Study Area Topography

Figure: 3-3

Rev: A

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Figure 3-4 Purari River Main Channel (July 2016)



Figure 3-5 Clear Tributary Stream (Boa Creek) Within PRL-15 (February 2017)



Figure 3-6 Purari Delta Floodplain (July 2016)



Figure 3-7 Purari River Floodplain South of PRL-15 (February 2017)

Bourke and Harwood (2009) examined seasonal rainfall patterns in Papua New Guinea, and classified the study area as *no seasonality, continuously heavy zone*, where the range in rainfall is below 100 mm per month, and is generally greater than 200 mm per month year round. There is great spatial variability in rainfall patterns, as further described in Section 6.

3.3 Geomorphological Setting

The Purari River catchment has a geomorphological setting reflective of its sediment producing capabilities and diverse topography. The inland southern fold mountains (mid parts of the catchment) are comprised of exceedingly steep erodible escarpments with steep ridges that are conducive to landslides. When combined with high annual rainfalls (from 3,500 to 8,000 mm), this mountainous region produces the greatest amount of sediment load transported by the Purari River system (Pickup and Chewings, 1983).

The upper reaches of the Purari River catchment (in the central highlands extending from Mendi to Goroka) are comprised of more stable sediments covered by dense vegetation. The volcanic ash covered slopes of the inland highland valleys give rise to some sediment loads; however, as sediment transport rates are closely aligned to runoff in the catchment, the lower annual rainfall in these areas results in lower sediment loads being transported by the system by comparison to areas further downstream.

3.4 Anthropogenic Setting

The following provides an overview of the anthropogenic setting of the study area, including population distribution and aquatic-based activities. More detailed information is provided in the Upstream Community and Demographics Baseline Report (Finlayson, 2017; Part 14 of ESBS Dossier) and Land and Natural Resources Use (Ecosystem Services – Provisioning) Baseline Report (Booyong Forest Science, 2017; Part 18 of ESBS Dossier).

The predominant land uses within the Purari River catchment generally fall into one of two categories: 1) undisturbed forest, broadly corresponding with the extent of the southern fold mountains, and 2) cleared rural areas, corresponding with highland valleys further inland. The inland southern fold mountains surrounding the mid reaches of the catchment are steep, highly erodible, and have a higher proportion of naturally exacerbated sediment transport. In contrast, the highland valleys are more stable and have a greater coverage of vegetation, such as anthropogenic grasslands. These land use categories contribute to sediment transport and sediment generation processes, and generally dictate the contribution of sediment from a particular sub-catchment.

The general area of PRL-15 in the Purari River catchment is characterized by low population densities. The Elk-Antelope gasfields and PRL-15 area are used by Pawaians.

Low population density in PRL-15 has meant there has been little agricultural pressure on the land, and the vast majority of Pawaian land remains covered by primary forest. Pawaian subsistence is largely practiced on the move in small mobile family or extended family groups operating from bush camps. Sago cultivation is the principal staple in the lowland areas, with production restricted to the river zones (e.g. Purari River and its tributaries). Sago is supplemented by other riverine foods, including fish and prawns.

The export pipeline corridor south of PRL-15 is largely unpopulated however has been modified by large-scale industrial logging. The Gulf Province coastal region and the onshore export pipeline corridor near the coast features a generally low inland population scattered or concentrated in small villages along riverbanks, and a much denser population in large villages and hamlets along the coastal strip. Seven of the principal villages in this area are: Evara, Mapaio, Aivai, Akoma, Aiope, Harevavo and Hororo.

The more remote inland communities rely almost entirely on native flora and fauna for their livelihoods and wellbeing. The people in this region practice a variety of subsistence activities including sago cultivation and production, swidden gardening of sweet potato, yam, taro, banana, cassava/tapioca, pawpaw and sugarcane, cultivation of trees (e.g. coconuts), pig husbandry, hunting and trapping, and fishing. Market opportunities limit the production of cash crops at a village level and almost all colonial era copra and rubber plantations have closed.

4 Existing Information

The following section describes the previous studies that are considered relevant to the study area. The actual content of this literature has been integrated, as relevant, into the findings described in Section 6.

4.1 Prior Studies within the Study Area

4.1.1 Published Report

Table 4-1 summarizes all the significant previous environmental impact assessment studies conducted within the study area (and neighboring regions). These represent a significant body of existing information relevant to the study area which has been used in the preparation of this report. NOTE: This section considers only published reports; unpublished reports are discussed in Section 4.1.2.

In addition to the studies listed in Table 4-1, Petr (1983) published a series of papers for the Purari River, based on the findings of the 1979 EIS for the Purari River Hydropower Project. The papers from this series considered relevant to this ESBS report are:

- Evesson, DT (1983), 'The climate of the Purari River basin'
- Pickup, G and Chewings, VH (1983), 'The hydrology of the Purari and its environmental implications' – this report cites findings from the following:
  - Snowy Mountains Engineering Corporation – Nippon Koei (1977), *Purari River Wabo Power Project Feasibility Report*, Vol. 6
  - Carter, JH (1980), 'Discharge data for the Purari River and some of its tributaries', in Viner (ed.), *Purari River (Wabo) Hydroelectric Scheme Environmental Studies*, Vol. 16
- Pickup, G (1983), 'Sedimentation processes in the Purari River upstream of the delta'.

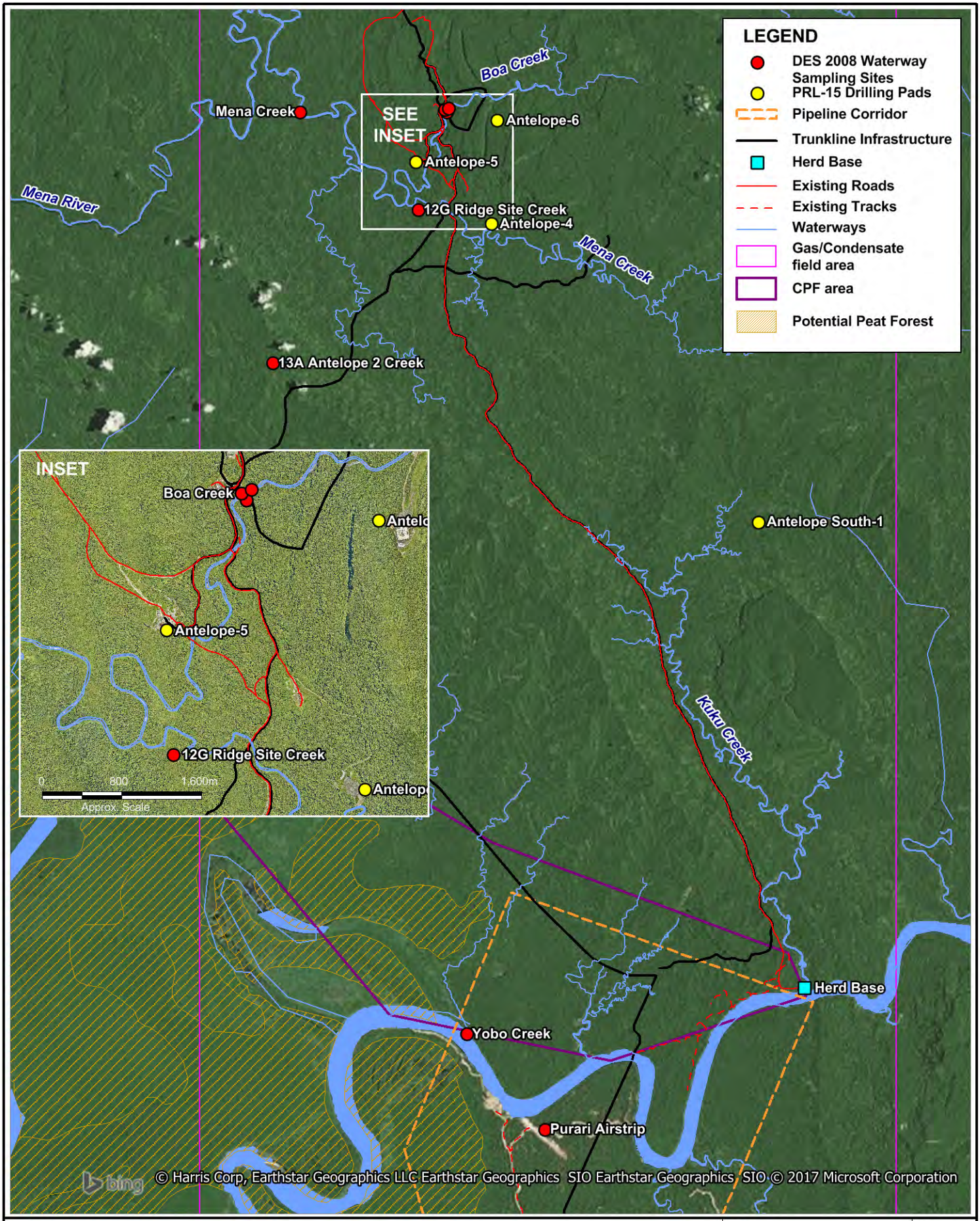
Both Pickup and Chewings (1983) and Pickup (1983) have undertaken some hydrological and sediment transport modeling for the study area.

The survey sites from studies that overlap with the study area are shown in the following figures:

- Figure 4-1 – stream sampling (flow velocity and stream-width) at various streams in PRL-15 (DES, 2008) and localized hydrology descriptions for PRL-15 drilling pads (GHD, 2015a, 2015b, 2015c, 2015d)
- Figure 4-2 – Purari River cross-sections (Pickup and Chewings, 1983).

Table 4-1 Summary of Previous Relevant Environmental Assessment Studies

Project/study	Year	Author	Geographic overlap	Relevance to ESBS	Relevant reports
Elk/Antelope Gasfield Project EIS (prepared for InterOil)	2008	Douglas Environmental Services (DES)	PRL-15 and adjoining areas	Detailed hydrology and meteorology information for all PRL-15 and Purari River	Elk/Antelope Gasfield Project Environmental Impact Statement (DES, 2008)
Environmental Impact Assessments and Environmental Management Plans for: • Antelope-4 • Antelope-5 • Antelope-6 • Antelope South-1	2015	GHD	Drilling sites in PRL-15	Preliminary hydrological information for drilling sites within PRL-15	Antelope-4 Environmental Impact Assessment and Environmental Management Plan Antelope-5 Environmental Impact Assessment and Environmental Management Plan Antelope-6 Environmental Impact Assessment and Environmental Management Plan Antelope South-1 Environmental Impact Assessment and Environmental Management Plan
Purari River (Wabo) Hydroelectric Scheme Environmental Studies	1979	Papua New Guinea Government	PRL-15 and Purari River	Detailed hydrology and meteorology information for PRL-15 and Purari River.	No reports available – results summarized in Petr (1983)



Title:

PRL-15 Waterway Sampling Sites – Elk/Antelope Gasfield Project EIS (DES, 2008) and Drilling Pads Assessed by GHD (2015a to 2015d)

Figure: 4-1

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Approx. Scale

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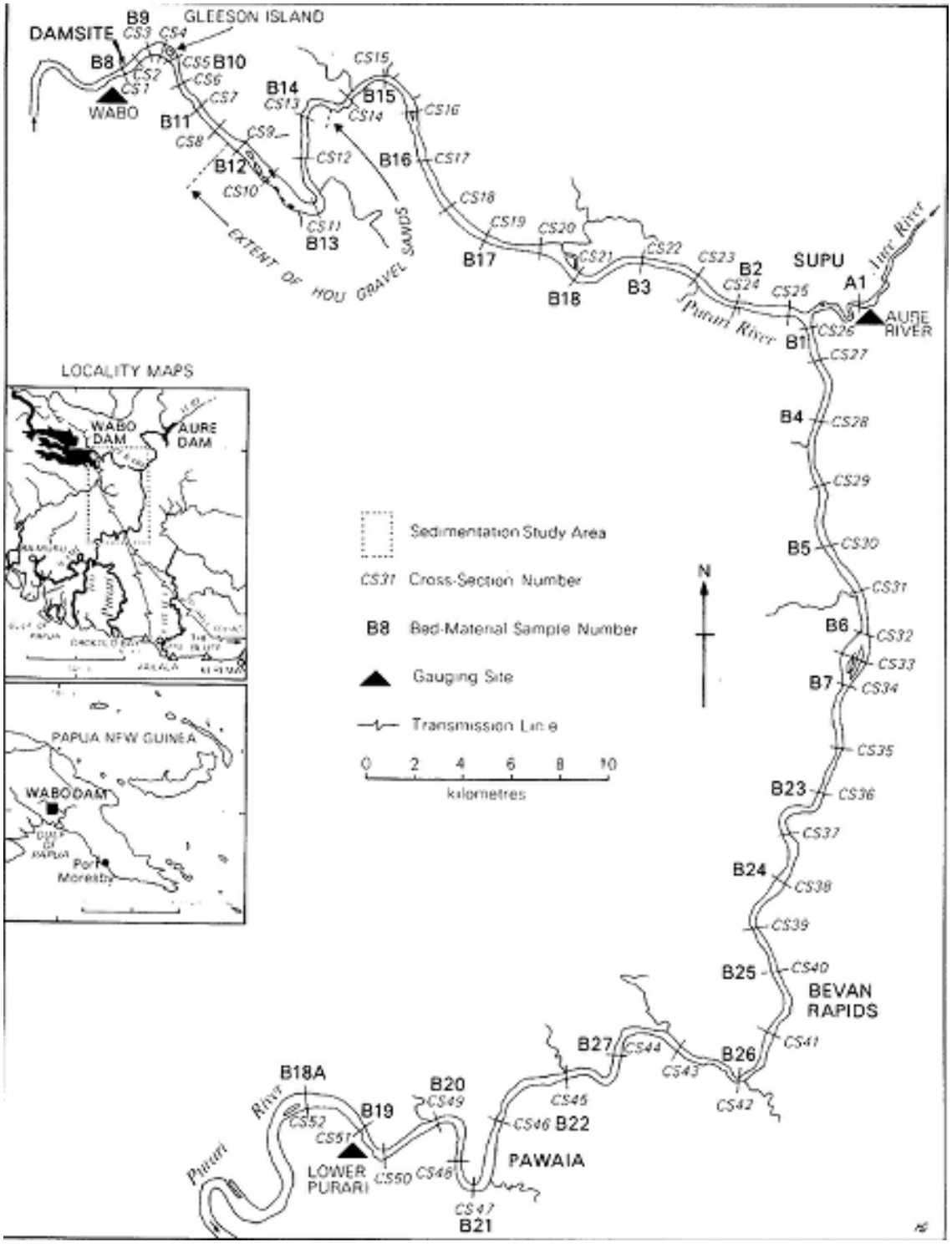


Figure 4-2 Purari River Cross-section Sites – Purari River (Wabo) Hydroelectric Scheme Environmental Studies (Pickup, 1983)

4.1.2 Unpublished Reports

In addition to the published reports discussed in Section 4.1.1, the other studies known to have occurred in the study area, but which have not been published, consist of:

- Hydrological investigations for an environmental impact assessment of a revised version of the Purari River hydropower project.
- High-level hydrological and sedimentology investigations (e.g. rainfall-runoff analysis, stream flow calculations, discharge regime, sediment transport) of waterways and parts of the Purari River within PRL-15.

4.1.3 Hydrological and Meteorological Data Collection

The following datasets relevant to hydrology and meteorology are known to exist for the study area and have been obtained to inform this baseline report:

- Rainfall and stream gauging stations managed by the (former) Bureau of Water Resources.
- Other rainfall and river level gauging stations installed by InterOil/TEP PNG within PRL-15.
- Regional weather stations.
- Purari River bathymetry and sub-bottom profiling data.
- Light Detection and Ranging (LiDAR) topographic data and digital elevation model (DEM).
- Shuttle Radar Topography Mission (SRTM) topographic data.
- High resolution weather model developed by BMT ARGOSS for Caution Bay.

These are described further below.

4.1.3.1 Rainfall and Stream Gauging Stations

Government Gauging Stations

Between 1961 and 1990 the (former) Bureau of Water Resources maintained a number of meteorological observation stations in the Purari River catchment. These are described in Table 4-2 and shown in Figure 4-3. These stations provide relevant data for understanding meteorological conditions across the catchment.

Pickup and Chewings (1983) also suggest that an additional gauging station has previously been located on the Purari River, near the entrance to the PRL-15 oxbow wetlands (‘Lower Purari’; see Figure 4-2 and Figure 4-3). The nature of data collected by this gauge and the availability of this data is unknown.

No known gauging stations have historically been located within the Pie or Era river catchments.

Table 4-2 Government Rainfall and Streamflow Data Collection Stations in Purari River Catchment

No.	Station	Elevation (m)	Location	Data collected and period	
702710	Gumants	2,120	-5.78510º, 144.2245º	Rainfall	1965-1984
702860	Muga	1,830	-5.64646º, 144.3334º	Rainfall	1965-1978
704300	Chimbu	1,400	-6.03418º, 144.9726º	Rainfall	1961-1976
705090	Asaro	1,920	-5.97192º, 145.2736º	Rainfall	1971-1990
711850	Auri	31	-7.05632º, 145.3423º	Rainfall	1970-1990
712400	Purari	40	-7.00022º, 145.0500º	Rainfall	1962-1989
				Streamflow	1958
703880	Waghi	3,400	-5.99328º, 143.9518º	Streamflow	1967-1980
709980	Kaugel	560	-6.35781º, 144.5504º	Streamflow	1975
708490	Tua	1,990	-5.55245º, 144.7641º	Streamflow	1975
710650	Erave	Unknown – located on Erave River		Streamflow	1966
-	Lower Purari	20-50	~-7.384º, 145.153º	Unknown	

In addition to these stations, McAlpine *et al.* (1983) has identified the stations listed below within the Purari River catchment:

- Erave (Station No. 200188); assumed to be the same as Erave (Station No. 710650) – 14 years of rainfall data (1956-1970).
- Wabo Dam Site (Station No. 200673); assumed to be the same as Purari (Station No. 712400) – two years of rainfall data
- Kuk (DPI Station) – US Class A Pan evaporation estimates.
- Mt Hagen (Station No. 200243) – 20 years of rainfall data (1951-1970), monthly temperatures, relative humidity and US Class A Pan evaporation estimates
- Mendi (Station No. 200339) – 14 years of rainfall data (1956-1970)
- Goroka A/S (Station No. 200197) – 19 years of rainfall data (1951-1970), monthly and probable temperatures, relative humidity, sunshine hours and US Class A Pan evaporation estimates
- Aiyura (Station No. 200003) – 29 years of rainfall data, relative humidity, sunshine hours and US Class A Pan evaporation estimates.
- Ialibu (Station No. 200314) – 13 years of rainfall data
- Kundiawa (Station No. 200182) – 13 years of rainfall data.

The approximate locations of these stations have been plotted on Figure 4-3 (except where the same as stations noted in Table 4-2).

Some station data is also available for Kerema (Station no. 200051), as published in Ruxton *et al*. (1969) and Kikori (Station No. 200054), published in Evesson (1983). These have been included in Figure 4-3.

Additional Gauging Stations

In addition to the government gauging stations discuss above, a rainfall and river level gauge has been installed at Herd Base, with additional gauging stations at the Antelope-3 staging camp, Antelope-7 exploration site, and at Hou Creek. The data collected by these stations and their location is described in Table 4-3. These sites are included in Figure 4-3.

Table 4-3 InterOil/TEP PNG Rainfall and River Level Data Collection Stations in PRL-15

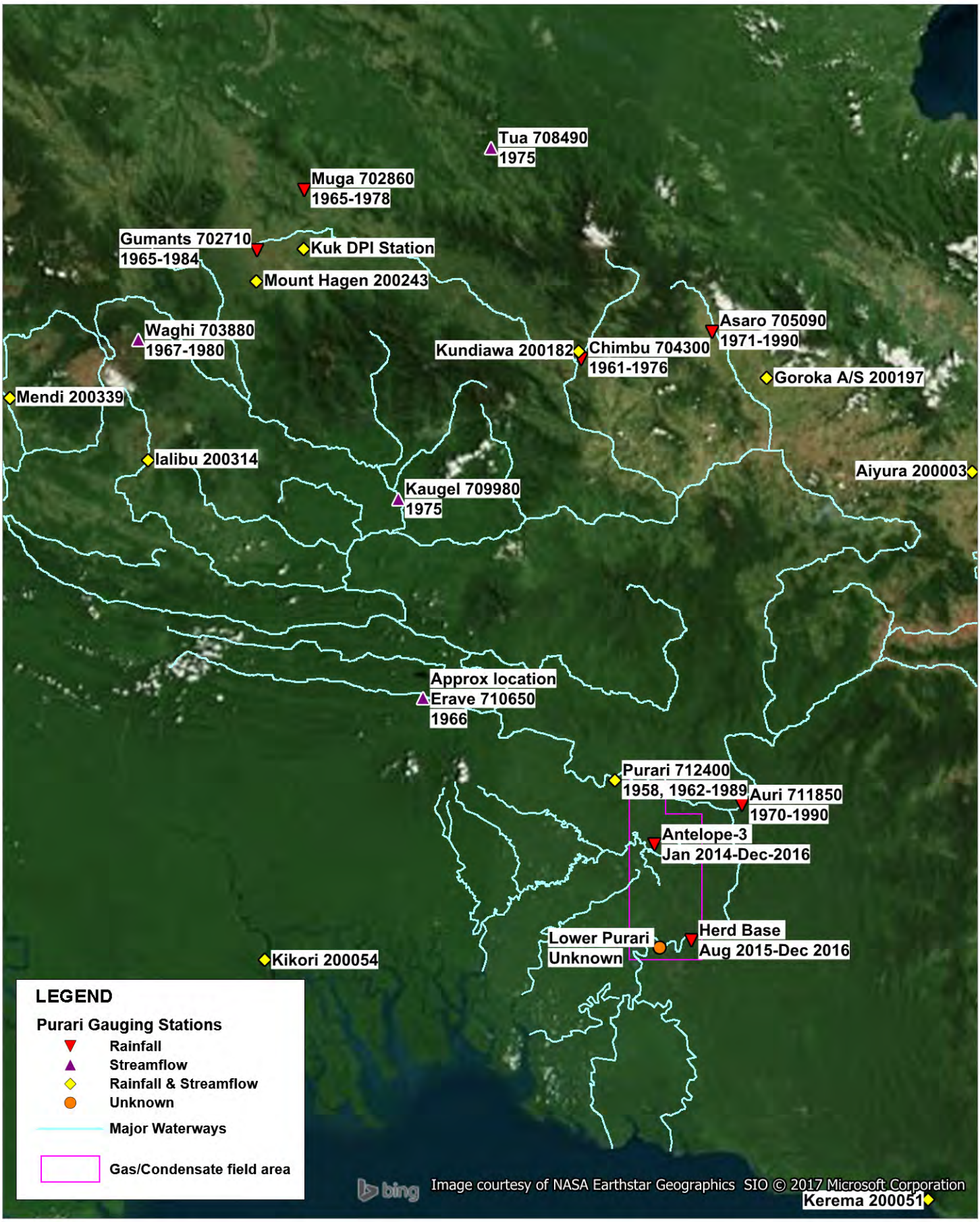
Station	Elevation (m)	Location	Data collected and period	
Herd Base	~40	-7.36510º, 145.2254º	Rainfall	Aug 2015-Dec 2016
			River level	2013-2015
Antelope-3	~110	-7.14657º, 145.1410º	Rainfall	Jan 2009-Dec-2009 Jan-Dec 2011 Jan 2014-Dec-2016
Antelope 7	~100	(approximate) -7.15387º, 145.1248º	Rainfall	Jan-Sep 2016
Hou Creek	~90	(approximate) -7.05752º, 145.33458º	Rainfall	Jan 2013-Sep 2014
			River level	Jan 2013-Sep 2014

4.1.3.2 Weather Gauging Stations

A number of weather stations occur in areas around the Gulf of Papua, providing data on wind patterns (e.g. direction, speed) and other meteorological data (e.g. air temperature, humidity). These stations are summarized in Table 4-4 and included in Figure 4-4.

Table 4-4 Weather Gauging Stations in the Region of the Study Area

Station	Elevation (m)	Location	Data collected and period	
Jacksons Airport, Port Moresby	137	-9.44º, 147,2275º	Temperature Relative humidity Wind speed Wind direction Rainfall Barometric pressure Solar radiation	Apr 2013-May 2015
Gerehu, Port Moresby	149	-9.4123º, 147.1603º		Feb 2011-May 2015
Mt Hagen	1,790	-5.82907º, 144.37415º		Nov-2011-May 2015
Kerema	148	-7.98933º, 145.79044º		Sep 2011-Dec 2015
Wabo	443	-7.00666º, 145.07303º		May 2013-Dec 2015



Title:

Purari River Catchment Rainfall and Streamflow Stations

Figure: 4-3

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Approx. Scale

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Title:

Regional Weather Stations

Figure: 4-4

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4.1.3.3 Regional Weather Modeling

A high resolution weather model simulation has been undertaken by BMT ARGOSS for TOTAL, focused on the area of the PRL-15 well pads and Orokolo Bay. This model was established to provide high resolution wind and weather data for these areas. This data is intended to be used for analysis of climatological conditions and to perform air dispersion modeling.

The model was developed using the regional atmosphere model WRF. The model was initially set up for Caution Bay and validated against meteorological data from the Jackson Airport weather station (see above) and the Australian Horn Island station (BMT ARGOSS, 2014). Ten years of simulation was then produced for the period 2004-2013 at a 3 km resolution for the following sites relevant to this study:

- PRL-15 well pads (Antelope-5, Antelope-2, Antelope-3, Elk-1).
- The Bluff (near Kerema).
- Oiapu 2.
- Caution Bay.
- Herd Base.
- Orokolo Bay.

The location of these data sites are shown in Figure 4-5.

The methodology and datasets used for the initial setup of the model is described in BMT ARGOSS (2014). Reports on model results for the 10-year simulation at well pads, The Bluff, Oiapu, Caution Bay and Herd Base are provided in BMT ARGOSS (2015a) and Orokolo Bay within BMT ARGOSS (2015b).

The datasets produced from this modeling consist of air temperature, air pressure, relative humidity, rainfall, surface temperature, ambient wind statistics and persistency, extreme wind statistics, water temperature, salinity, and tides.

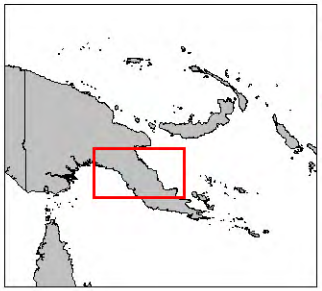
4.1.3.4 Bathymetry and Topography

Topography

LiDAR data has been captured for the study area, including the onshore export pipeline corridor and within PRL-15. This LiDAR has been converted into a DEM to show the topography of these parts of the study area. Data within PRL-15 is to a 1 m resolution (i.e. 1 m tiles) while the export pipeline corridor is to 2 m.

In addition to LiDAR, topography data is available from the SRTM for the entire study area. However, this data is based on 30 m tiles (based on satellite sampling over a grid of 1 arc-second by 1 arc-second) and is therefore coarser than a LiDAR-derived DEM. The linear vertical absolute height error of the SRTM topography is less than 16 m and the linear vertical relative height less than 10 m.





LEGEND

- Location of Interest
- PRL-15 Boundary

Title:

Locations of Interest for BMT ARGOSS Regional Weather Modeling

Figure: 4-5

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Scale - Main Map

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Bathymetry

Bathymetric data was collected within the Purari River as part of a survey campaign between the coast and Henaru (Herd Base), approximately 110 km upstream (unpublished report). This survey collected single-beam data (collecting bathymetry for a single centerline) within the river as well as multi-beam data (collecting a broad swathe of bathymetry) at Herd Base. The report also includes two cross-sections upstream and downstream of Herd Base.

Additional survey data has been provided by TEP PNG from the IOC showing bathymetry in the Purari River from the coast to the mouth of Hou Creek. This survey covers all three branches of the Purari within the delta, i.e. Purari, Urika-Ivo and Wame-Varoi, and maps bathymetry based on areas greater than and less than 5 m in depth.

4.2 Studies in Neighboring Regions

The known EIS and other studies that have been conducted in areas adjoining or near the study area consist of the following:

- PNG LNG Project EIS (CNS, 2009) – this project involves gas extraction in Hela and Western provinces, with an onshore pipeline to the Kikori River and an offshore pipeline through the Gulf of Papua to Caution Bay. This EIS provides comparative hydrology, meteorology and sedimentology information from an adjoining province, albeit in a different biophysical environment.
- P'nyang Project EIS (CNS, 2015) – this project is an extension of the PNG LNG Project, involving gas extraction from the P'nyang gas fields in Western Province and an onshore pipeline to existing facilities used by the PNG LNG Project. This EIS provides comparative hydrology, meteorology and sedimentology information from an adjoining province, albeit in a different biophysical environment.

4.3 Summary

There is a range of existing information for the study area in regards to understanding basic hydrology, meteorology and sedimentology, including indicative climatology, rainfall and stream flow data. However, this data is mostly qualitative in nature and features the following gaps/limitations:

- While Pickup and Chewings (1983) have undertaken some hydrologic modeling for the study area, this was designed to support a hydropower assessment and therefore focused on regular flow events, i.e. events with an average recurrence interval (ARI) less than 20 years. This is not sufficient for the purposes of determining the inundation extent and depth associated with larger ARI events which could occur over the lifetime of the Project.
- Similarly, there is no data available in regards to flooding (i.e. hydraulics) from the Purari River.
- Previous modeling of sediment yield and sediment transport has been based on event hydrology rather than a range of rainfall conditions during wet and dry season or over a continuous period whereby average annual flow and total suspended sediment (TSS) load could be estimated.

5 Approach and Methods

5.1 General Approach

In approaching the characterization of the baseline environment, the study was separated into the following elements:

- Climate/meteorology – this element focuses on weather and rainfall patterns, temperature, evaporation, and runoff.
- Hydrology and hydraulics – this element focuses on flow of surface water within the study area, including likely flows associated with different rainfall events and the flooding associated with these events.
- Sediment loads and transport – this element generally focuses on sediment yield and transport within waterways, including the availability of terrestrial sediment that could be mobilized by fluvial processes.

The assessment of all three elements involved a review of existing literature and data, with additional numerical modeling undertaken for hydrology, hydraulics and sediment loads and transport. Literature/data review focused on providing a high-level characterization of the study area while numerical modeling was utilized to provide more detail about specific fluvial processes relevant to the Project.

Complete details of numerical modeling activities are provided within the Waterways Modeling Report (Appendix A) but are also described below.

5.1.1 Modeling Approach for Hydrology and Hydraulics

Modeling for hydrology and hydraulics was based on two linked modeling activities:

(1) *Hydrology Assessment*, including rainfall/flood frequency analysis, to quantify flow rates and volumes during design flood events.

(2) *Hydraulic Assessment* to identify flood behavior in the study area for the design events developed during the *Hydrology Assessment*.

Characterization of floodplain hydraulics is expected to underpin more detailed risk assessments for the Project as part of an impact assessment phase, including identification of the potential for contaminants, exposed soils and other materials to be mobilized within the study area during flood events, and identification of waterways of high scour risk. As an understanding of hydrology is considered necessary to underpin a hydraulic assessment, both hydrology and hydraulic modeling activities are required.

The *Hydrology Assessment* was based on a Unified River Basin Simulator (URBS) model using rainfall and flood frequency estimates derived from the Papua New Guinea Flood Estimation Manual (FEM) (SMEC, 1990) and locally relevant literature and data. Design events modeled as part of this assessment were the 10, 50 and 100 year ARI storms at key locations. Additional software packages used alongside URBS included CatchmentSIM (to derive sub-catchments for the Purari, Pie and Era river catchments) and Flike (to undertake a flood frequency analysis).

The *Hydraulic Assessment* combined the results of the *Hydrology Assessment* with a digital DEM. This assessment was conducted using a two-dimensional (2D) model set up using the TUFLOW hydrodynamic software package and modeled the same design events as for the *Hydrology Assessment*.

Both sets of models were uncalibrated and unvalidated due to paucity in locally available data, though where data was available it was utilized to assist in the refinement of the models. In order to further refine the URBS model, a flood frequency analysis was undertaken using gauging data from the Purari station (station number 712400). This analysis produced indicative hydrological data suitable for the purposes of partial calibration/validation of the model.

5.1.2 Modeling Approach for Sedimentology

For the purposes of the *Sedimentology Assessment* the eWater Source Modeling Framework ('Source Catchments')[1] was used to simulate rainfall-runoff processes within the Purari River catchment. This provides the basis for semi-quantitative assessments of sediment transport rates.

Source Catchments was used to develop a rainfall-runoff model (SIMHYD) simulating a continuous longer-term historical period (March 2000 to December 2015). This was then used to estimate the flow (runoff) volume and load of TSS for the Purari River catchment. This provides a baseline for flow regimes, flow volumes and TSS concentrations/loads that can be used for the purpose of impact assessment during later phases of the EIS/ESHIA.

The rainfall-runoff model was calibrated using historical streamflow datasets for the study area. These were the Purari, Asaro and Chimbu stations for rainfall (1962-1989, 1961-1976 and 1971-1990, respectively) and Waghi station for streamflow (1967-1980) due to the overlapping data periods from these gauges (i.e. 1967/71-1980). Further information on gauge data is provided in Section 5.2.

5.1.3 Field Data Collection

No detailed data collection exercises or instrument installations have been undertaken to inform either hydrology/hydraulic or sedimentology studies. However, opportunistic data collection was undertaken as part of field surveys for the Upstream Freshwater and Estuarine Biodiversity Baseline Report (BMT WBM, 2017b) and Upstream Surface Water and Sediment Quality Baseline Report (BMT WBM, 2017a; Part 3 of ESBS Dossier). This consisted of collection of water quality data and (limited) stream level data for the Purari River at Herd Base.

5.2 Data Sources

5.2.1 Datasets

The key data sources used for preparing this report, particularly in the context of modeling, were:

- Bureau of Water Resources gauging data (provided by CEPA) for (see Figure 4-3):
  - Purari station (712400) – 1962-1989 (rainfall) and 1958 (streamflow).
  - Waghi station (703880) – 1967-1980 (streamflow).

[1] http://www.ewater.com.au/products/ewater-source/

- Asaro station (704300) – 1961-1976 (rainfall).
- Chimbu station (705090) – 1971-1990 (rainfall).

- PRL-15 rainfall and river level data (provided by TEP PNG) for (see Figure 4-3):
  - Herd Base – rainfall: August 2015 to December 2016; river-level: January 2013 to June 2016.
  - Antelope-3 – January to December 2009, January to February 2011, and January 2014 to December 2016.
  - Antelope 7 – rainfall: January to September 2016
  - Hou Creek – rainfall/river level: January 2013 to September 2014.
- Gauging station data reported in Ruxton *et al.* (1969), McAlpine *et al.* (1983) and Evesson (1983) for (see Figure 4-3):
  - Erave station (200188).
  - Wabo Dam site station (200673).
  - Kuk (DPI Station).
  - Mt Hagen station (200243).
  - Mendi station (200339).
  - Goroka A/S station (200197).
  - Aiyura station (200003).
  - Ialibu station (200314).
  - Kundiawa station (200182).
  - Kerema station (200051).
  - Kikori station (200054).
- Modeled results published by Pickup and Chewings (1983) and Pickup (1983), including flow duration curves and sediment rating curves for the Purari and Aure rivers.
- Australian Rainfall and Runoff – Online Data Hub (http://arr.ga.gov.au/downloads-and-software/data), which provides design rainfall input parameters required to undertake flood estimation in Australia.
- Australian Bureau of Meteorology - 2016 Rainfall Intensity Frequency Duration Data System.
- Stream level:
  - Field data collected February 2017.
- Weather station data (provided by TEP PNG), including temperature, relative humidity, wind speed, wind direction, rainfall, barometric pressure and solar radiation, for (Figure 4-4):
  - Jacksons Airport – April 2013 to May 2015.

- Gerehu – February 2011 to May 2015.
- Mt Hagen – November 2011 to May 2015.
- Kerema – September 2011 to December 2015.
- Wabo – May 2013 to December 2015.

- Simulated weather data (air temperature, air pressure, relative humidity, rainfall, surface temperature, ambient wind statistics and persistency, extreme wind statistics) for 2004 to 2013, derived from a regional weather model developed by BMT ARGOSS (provided by TEP PNG) for (Figure 4-5):
  - PRL-15 well pads (BMT ARGOSS, 2015a).
  - Well pad Antelope-5 (BMT ARGOSS, 2015a).
  - Well pad Antelope-2 (BMT ARGOSS, 2015a).
  - Well pad Antelope-3 (BMT ARGOSS, 2015a).
  - Well pad Elk-1 (BMT ARGOSS, 2015a).
  - Orokolo Bay (BMT ARGOSS, 2015b).
- Topography:
  - Light Detection and Ranging (LiDAR) elevation data supplied by TEP PNG:
    - DEM_001_170130_1m_PRL_15.
    - DEM_003_170130_2m_ExportCorridor.
  - Shuttle Radar Telemetry Mission (SRTM) elevation data.
- Summary of multi-beam and single-beam profiling for Purari River between coast and Henaru (Herd Base), (unpublished report, 2010).
- Mapped bathymetry for Purari River between Hou Creek mouth and the coast, including bathymetry for Purari, Urika-Ivo and Wame-Varoi rivers, based on areas of greater than and less than 5 m depth.
- Cross-sections for two locations, i.e. upstream and downstream of Herd Base.

These datasets are in addition to literature discussed in Section 4 and referenced in Section 10. As noted in Section 5.1.2, calibration/validation data was used from the Purari, Waghi, Asaro and Chimbu gauging stations. While other gauge data was available (see Section 4.1.2) none of this data presented coincident rainfall and streamflow relevant to the study area. Overlapping periods of streamflow (level and discharge) and rainfall data is required to calibrate hydrologic and hydraulic models. The recorded rainfall data is used in the hydrologic models to produce runoff estimates (discharges). These discharges are then related to the records at the stream gauges and a comparison between the modeled and the recorded discharges is made. The parameters of the hydrologic model are subsequently adjusted so the discharges in the model match closely with the recorded discharges.

The LiDAR ground elevation data is highly accurate and of a fine resolution. However, it does not provide bed elevations within channels/depressions that contain water as LiDAR sensing techniques cannot penetrate deep water. It also can be potentially inaccurate in areas of very dense vegetation. As such, the water level of the main Purari River channel in the LiDAR data set was assumed to be 4.8 m for the reach within the vicinity of Herd Base.

The SRTM data has a 30 m grid resolution due to sampling over a grid of 1 arc-second by 1 arc-second (approximately 30 m by 30 m). It has a linear vertical absolute height error of less than 16 m, and a linear vertical relative height error of less than 10 m.

5.2.2 Data Quality Assurance/Quality Control

Datasets listed in Section 5.2.1 utilized in the modeling were subject to quality assurance/quality control (QA/QC) procedures which involved the following:

- Visual inspection of data.
- Review of metadata associated with datasets.
- Pre-processing of data within relevant modeling packages to identify data gaps.
- Comparison of datasets between locations and data sources (where available).

5.3 Limitations

The following limitations in the study approach are noted:

- While gauged rainfall data is available within the catchment for a period of close to 30 years (i.e. Purari station 1962-1989), long-term data from a second gauging station within the study area was not available for rainfall or streamflow. Due to this data paucity, it was not possible to validate the hydrology and hydraulic models. In addition, insufficient data was available to undertake a detailed rainfall frequency analysis. Instead, the methodology provided in the FEM (SMEC, 1990) was utilized (see Section 6.4.2.2).
- Bathymetric data (including multiple cross-sections across various reaches of the river) was unavailable at the time of undertaking hydraulic modeling activities. As a result, a ‘generic’ channel profile for the Purari River has been adopted, based on previous experience with waterways in Papua New Guinea and results from cross-sections taken near Herd Base (cf. unpublished report, 2010).
- No modeling of prevailing geomorphological processes within study area waterways (e.g. stream movement) has been undertaken as these have been assumed to not be of concern as part of the Project EIS/ESHIA.
- No receiving water quality model (RWQM) has been developed for the purposes of characterizing existing water quality, particularly in relation to TSS. This was not considered necessary due to the naturally high volumes of sediment within the Purari River and the relatively small area expected to be subject to land-use conversion as a result of the Project (i.e. additional sediment loads likely to be mobilized will be relatively small and therefore can be assessed using a semi-quantitative method only).

- Whilst current industry practice techniques have been applied, the work relies on the use of theoretical runoff events. Whilst a flood frequency analysis has been undertaken for the Purari River upstream of Wabo Creek (based on gauge data), which is upstream of the site, no historic flood data within the model boundaries is available to verify flow characteristics at the site.
- For the purposes of establishing the Source Catchment model, uniform rainfall patterns, potential evapotranspiration rates, TSS generation and constituent loads have been applied for the area downstream of Hathor Gorge. This is as a result of a lack of spatially-distributed gauged/measured data for these parameters (i.e. there is insufficient gauge data downstream of Hathor Gorge from multiple locations).

Some of the above limitations (i.e. bathymetry, stream gauging data) are of particular relevance to modeling of hydraulic conditions in the Purari River between Herd Base and the Purari airstrip. This sub-catchment is considered to be important as it contains the PRL-15 oxbow wetlands. The connection of these wetlands to the Purari River can occur by inundation of tie-channels connecting the oxbow lake and the main river channel (i.e. river-based inundation), as represented in hydraulic modeling. However, as there is no bathymetry available within these tie channels, the ability of models to accurately predict connectivity on a regular basis (i.e. annually and sub-annually is limited. For this reason, connectivity has only been modeled in relation to larger events (i.e. 10, 50 and 100 year ARI events).

These limitations and assumptions are not anticipated to impact on the ability to characterize the baseline hydrology and meteorology environment suitable for the preparation of an EIS/ESHIA. However, the results of this modeling present the desktop theoretical analysis of potential processes and should not be used to inform engineering activities.

6 Baseline Characterization

This section provides an overview of the hydrology and meteorology baseline for the study area. It includes a regional characterization of the study area as well as presentation of the results of the *Hydrology Assessment*, *Hydraulic Assessment* and *Catchment Modeling* for the study area. Specifically, this section sets out the following baseline information for the study area:

- Bathymetry of the Purari River.
- Climate, including wind patterns, temperature and rainfall/evaporation patterns.
- Hydrology, including information on river basins and catchments, rainfall-runoff and stream flow, and results of analysis for particular rainfall events.
- Results of a flood frequency analysis.
- Catchment flooding characteristics and results of specific sub-catchment hydraulic assessments.
- Catchment sediment loads.

A complete set of the modeling results described in this section is provided in Appendix A.

As most of the above information relates to the Purari, Era and Pie river catchments, together with more detail on the Purari River downstream of Hathor Gorge, high level descriptions of the hydrological features of sub-catchments in PRL-15 are also provided below. This should be read in conjunction with the Upstream Surface Water and Sediment Quality Baseline Report (BMT WBM, 2017a) and Upstream Freshwater and Estuarine Biodiversity Baseline Report (BMT WBM 2017b).

6.1 PRL-15 Waterways

The principal waterways of PRL-15 are the Mena River (and tributary creeks), Eia Creek, Hou Creek, and Kuku Creek. These are described below in the context of the catchment in which they occur. These waterways are shown in Figure 3-1.

NOTE: Catchment modeling (described in Sections 6.4.2.2 and 6.6.2) includes reporting locations within Hou Creek (Location 2), Boa Creek (Location 3), Mena River (Location 4) and Kuku Creek (Location 5).

Era River Catchment

The waterways of the Era River catchment drain most of central and western PRL-15, flowing southwest before discharging into the Gulf of Papua west of Port Romilly. The upper tributaries of the catchment are the Mena River and Boa and Toa creeks. The Mena River and its Boa Creek tributary drain from the Mena plateau, west of the Antelope 3 staging camp. The Toa Creek, draining from the ridges south of the Purari River between Hathor Gorge and Wabo, joins the Mena River approximately 9 km downstream of the confluence of the Boa Creek with the Mena River. The Mena River then joins with other tributaries to become the Era River, approximately 7 km west of PRL-15.

Flows within the Mena River catchment are described in Section 6.4.2. The Mena River catchment, including the Toa and Boa creek catchments, is 282 km^2.

Based on sub-catchment delineation, Boa Creek has a catchment area of 53 km^2. The mean daily flow through this area is 40 ML/day, with a mean annual flow of 2,635 ML/yr. GHD (2015b, 2015c) identified the mean flow of the creek as 32.4ML/day, based on a smaller sub-catchment area of 27 km^2. Flow in the catchment is derived from rainfall and therefore subject to high variability, however assessments by GHD (2015b, 2015c) indicate that the minimum discharge flow is not expected to fall below 60% of mean daily flow.

Mena River upstream of the Boa Creek confluence was estimated by GHD (2015a) to have a 92 km^2 catchment with a mean flow of 150 m^3/s. Similar to the Boa Creek, flow in this part of Mena River is derived from rainfall runoff, with minimum discharge flow not expected to fall below 60% of mean daily flow.

Based on sub-catchment delineation, Toa Creek has a catchment size of 52 km^2. This creek is also expected to have highly variable stream flow, derived solely from rainfall.

Pie River Catchment

The only sub-catchment of the Pie River catchment in PRL-15 is Eia Creek. This drains from the central western side of PRL-15, west of a small ridge that separates the sub-catchment from the Mena River sub-catchments to the northeast. While discharge volumes from Eia Creek are not available, Petr (1983) identifies the creek as have typically low flow resulting in negligible dilution impact on the Pie River. However, during periods of extremely high rainfall the creek is able to discharge substantial volumes of freshwater, causing the Pie River to have near freshwater surface conditions as far as Baimuru.

Based on catchment delineation (see Section 6.4.1), the catchment area of the Eia Creek is 365 km^2.

Purari River Catchment

The two principal waterways in PRL-15 that form part of the Purari River catchment are Hou and Kuku creeks. Hou Creek drains the northeast part of PRL-15, running east of the Mena plateau and discharging into the Purari River 10 km downstream of Wabo. Kuku Creek drains the southeastern part of PRL-15 (north of the Purari River), running west along the southern plateau and discharging at Herd Base.

Kuku Creek is fed by both rainfall and groundwater baseflows. GHD (2015b) records a small catchment area of 18 km^2, with an estimated daily flow of 3.5 ML/day (GHD, 2015b). Based on catchment delineation, however (see Section 6.4.1), this is expected to be only a tributary of the overall creek catchment. The flow from the entire catchment is discussed in Section 6.4.2. Based on sub-catchment delineation, Hou Creek has a catchment area of 136 km^2. Mean daily flow from this creek is 102 ML/day while mean annual flow is 36,791 ML/year.

6.2 Bathymetry

The Purari River from the mouth to upstream of PRL-15 is a wide meandering channel cut into sedimentary coastal plains (unpublished report, 2010). As a result, the river features significant scour on the outside of bends, forming a deep channel, with deposition of shallow sand and mud banks on inside bends. This has caused the creation of a continuous channel upstream as far as Herd Base. These findings are based on a navigational exercise conducted in November, i.e. the beginning of the northwest monsoon season, representing the 'dryer' time of year for PRL-15 (see Section 6.3.3). It was noted that a drop of the river by approximately 5 m, as appears to be possible based on anecdotal evidence, may cause restrictions within the channel.

Depth profiles from bathymetry surveys show significant changes in depth between parts of the river on the inside and outside of river bends. Within the delta, the Urika-Ivo channel is the widest anabranch with depths greater than 5 m, however the width of this channel narrows near the coastline. The Purari and Wame-Varoi channels, by contrast, while not providing as wide an area of deep channel, provide a continuous channel along their entire length.

A very shallow zone occurs at the mouth of the Purari channel, extending a width of 1.5 km just offshore of the coastline (unpublished report, 2010). Due to this bar, depths are less than 3 m during high tide. Coastal processes in this area are further described in the Seabed and Coastal Geomorphology Baseline Report (BMT WBM, 2017c; Part 9 of ESBS Dossier).

Upstream between Herd Base and the Aure River confluence, the IOC bathymetry shows the river is more confined, with less meandering. This has produced a more consistent area of deep channel, with only small areas of shallow banks and bars. Upstream of the Aure River, the river begins to meander again.

Measurements of cross-sections have been undertaken at two locations, to the east and to the west (exact location uncertain), of Herd Base (unpublished report, 2010). The eastern transect showed a U-shaped river profile with a uniform bed depth (comparative to local datum) between -11 and -13 m. The western transect, located downstream of the confluence of the Purari River and Kuku Creek, showed the presence of a sediment bank adjacent to the northern bank, with the bed in this area approximately 2 m higher than further upstream at the eastern transect site. This is expected to be caused by the sediment input of Kuku Creek. On the southern bank, there was significant scour with water depths extending to a depth of -20 m.

These transects, while probably no longer likely to represent the actual bathymetry in these areas, show typical cross-sections associated with the Purari River in the vicinity of Herd Base. In particular, this shows the influence of sediment inputs to bathymetry and indicates likely continual changes in bed profile due to movement of bed sediment.

6.3 Climate

6.3.1 Wind Patterns and Air Pressure

Two surface pressures systems influence wind and overall climate processes in southern Papua New Guinea (McAlpine *et al*. 1983):

- Southeast trade winds – which prevail from about May to October

- Northwest monsoon – which prevails from about December to March.

These wind streams are driven by the positioning of the subtropical high pressure belt and the ITCZ (Evesson, 1983; BMT ARGOSS, 2015a). During winter months, the ITCZ moves over Papua New Guinea while the subtropical high pressure belt moves over central Australia. This causes southeast trade winds to develop between both systems. During summer, both systems move southwards, leading to northwest monsoon.

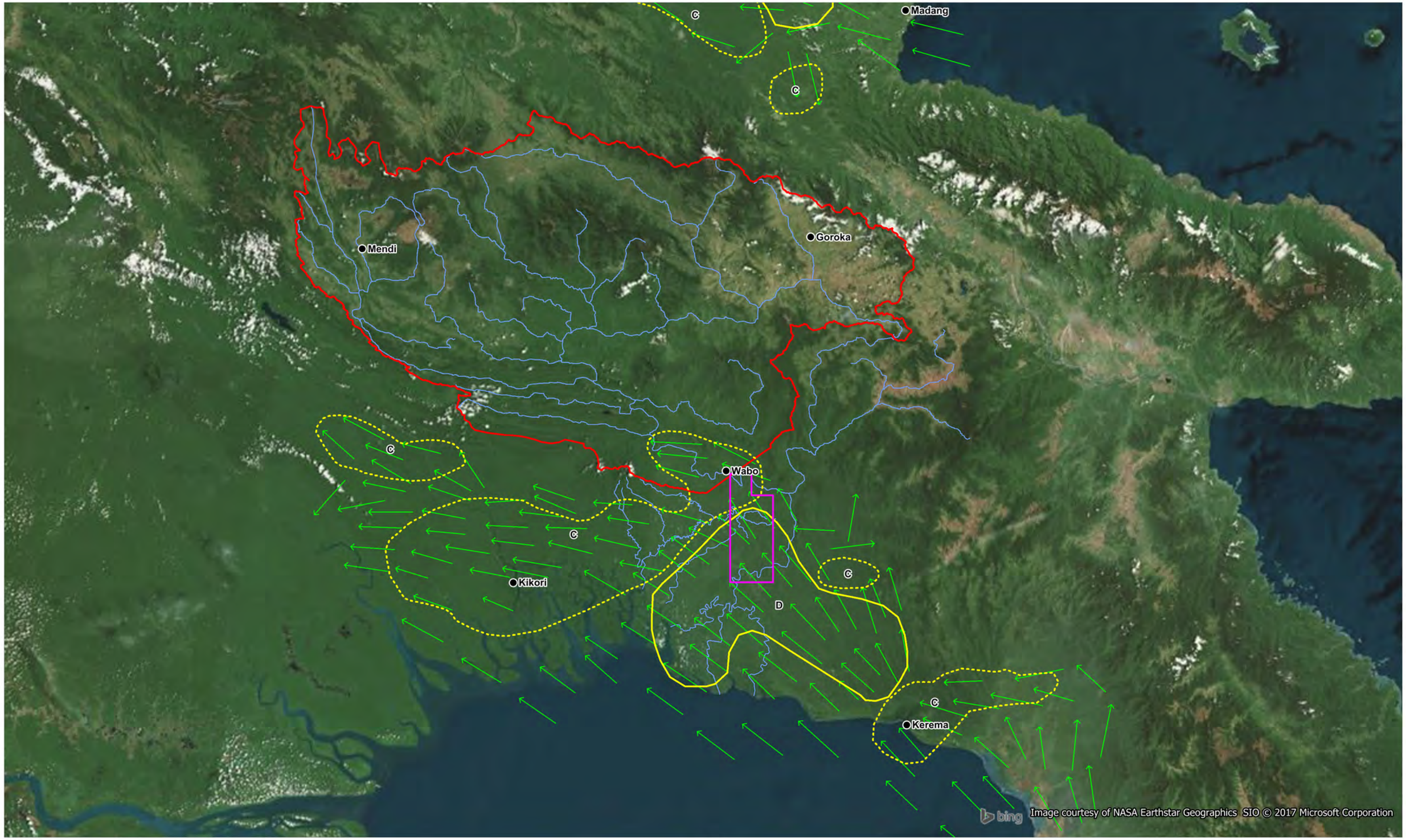
The southeast trade winds are the steadiest surface wind systems on earth, and are a critical driver of the conversion and transfer of water vapor and latent heat energy that drives global circulation (McAlpine *et al.* 1983). The southeast trade winds emanate from the subtropical ridge and extend towards the equator in a diverging stream. Winds at this time are moderate to fresh at 5 to 10 m/s, although strong winds of 12 to 15 m/s can also occur (BMT ARGOSS, 2015a). During this season there is windward and leeward rainfall effects on Papua New Guinea, producing very heavy rainfall on windward slopes facing the southeast and southern face of the central cordillera. Figure 6-1 shows the convergence and divergence zones that occur over the Purari River during this season.

A transitional period in November is characterized by the development of an equatorial trough (McAlpine *et al.* 1983). This leads to light variable surface winds, i.e. ‘doldrums’. Trade winds continue to blow within this time but have a weakened effect.

Following the November transition, the northwest monsoon forms following the southward movement of the ITCZ over Australia. This movement of the ITCZ causes the movement of the monsoon shear line southwards over Papua New Guinea and northern Australia (McAlpine *et al.* 1983). This brings winds from the northwest. Winds at this time are mainly low to moderate, with speeds of 2 to 6 m/s (BMT ARGOSS, 2015a). Figure 6-2 shows the convergence and divergence zones that occur over the Purari River during this season. Cyclones typically occur during the northwest monsoon season, although the study area is north of the main cyclone belt (BMT ARGOSS, 2015a).

Similar to November, April represents a transition marked by doldrums, following the northward movement of the ITCZ (McAlpine *et al.* 1983). However, the length of transition in April is variable, with the start of the southeast trade wind season varying between the start and end of April (Evesson, 1983). Showers still occur during this season but with decreasing frequency towards the end of the period. Winds range between 2 and 10 m/s, coming from a southeast direction towards the end of the period (BMT ARGOSS, 2015a).

Figure 6-3 contrasts wind roses (derived from BMT ARGOSS modeling) for Herd Base for months representative of the southeast trade wind season (July) and northwest monsoon (January). Figure 6-4 provides annual wind roses for PRL-15 well pads and Orokolo Bay.





LEGEND

- PRL-15 Boundary
- Purari River Catchment above Wabo
- Waterways

Wind Patterns *

- C — Convergence
- D — Divergence
- Wind Direction

* Wind Pattern Data digitised from hard copy map (Evesson, 1983)

Title:

May to October Wind Patterns Over the Purari River Catchment (Reproduced from Evesson, 1983)

Figure: 6-1

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 25 50km

Approx. Scale

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Madang
Mendi
Goroka
Wabo
Kikori
Kerema
C
D
Image courtesy of NASA Earthstar Geographics SIO © 2017 Microsoft Corporation



LEGEND

PRL-15 Boundary

Purari River Catchment above Wabo

Waterways

Wind Patterns *

C Convergence

D Divergence

Wind Direction

* Wind Pattern Data digitised from hard copy map (Evesson, 1983)

Title:

December to March Wind Patterns Over the Purari River Catchment (Reproduced from Evesson, 1983)

Figure: 6-2

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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Approx. Scale

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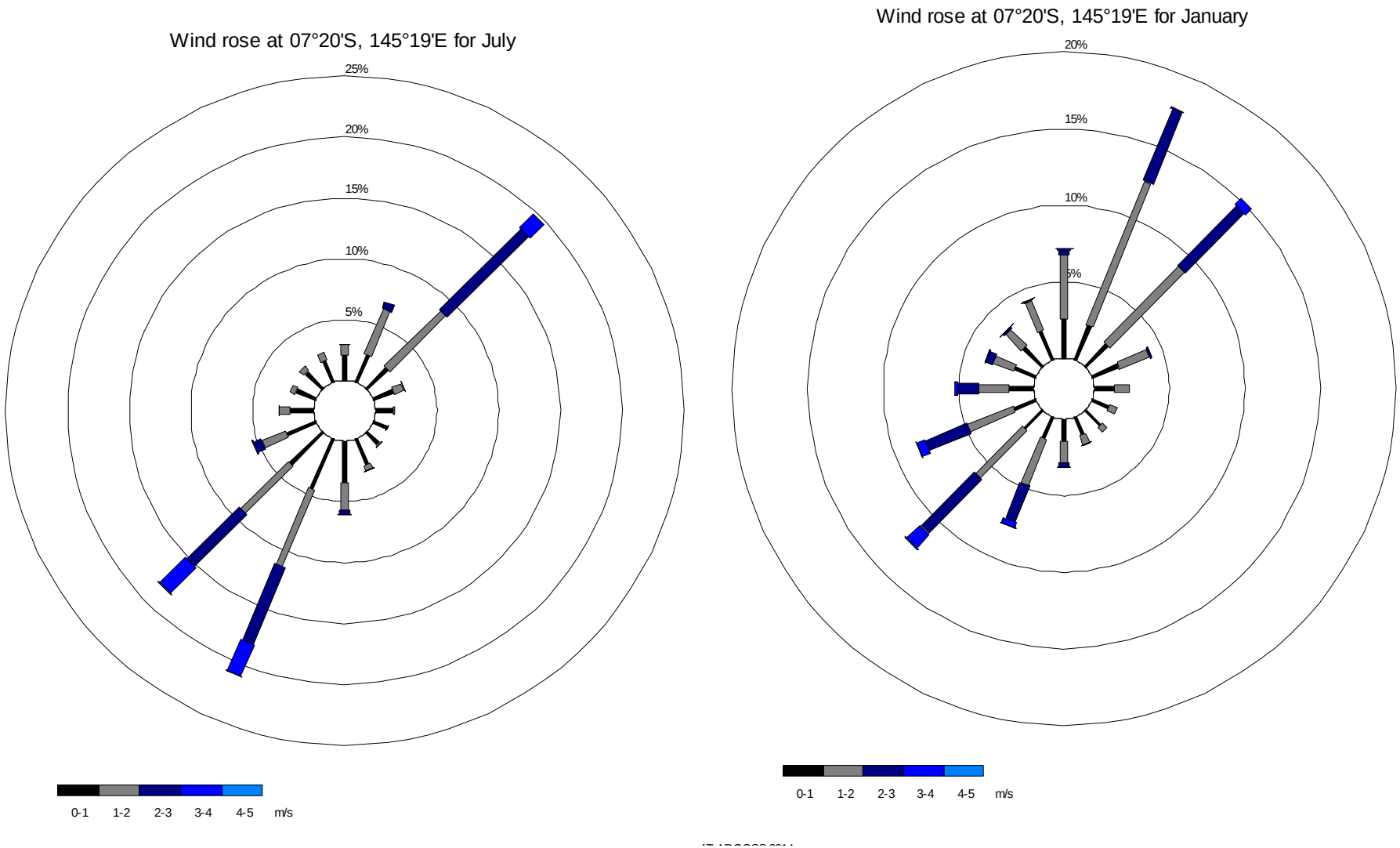


Figure 6-3 Wind Roses for Herd Base in Different Seasons: southeast trade winds (July – left) and northwest monsoon (January – right)

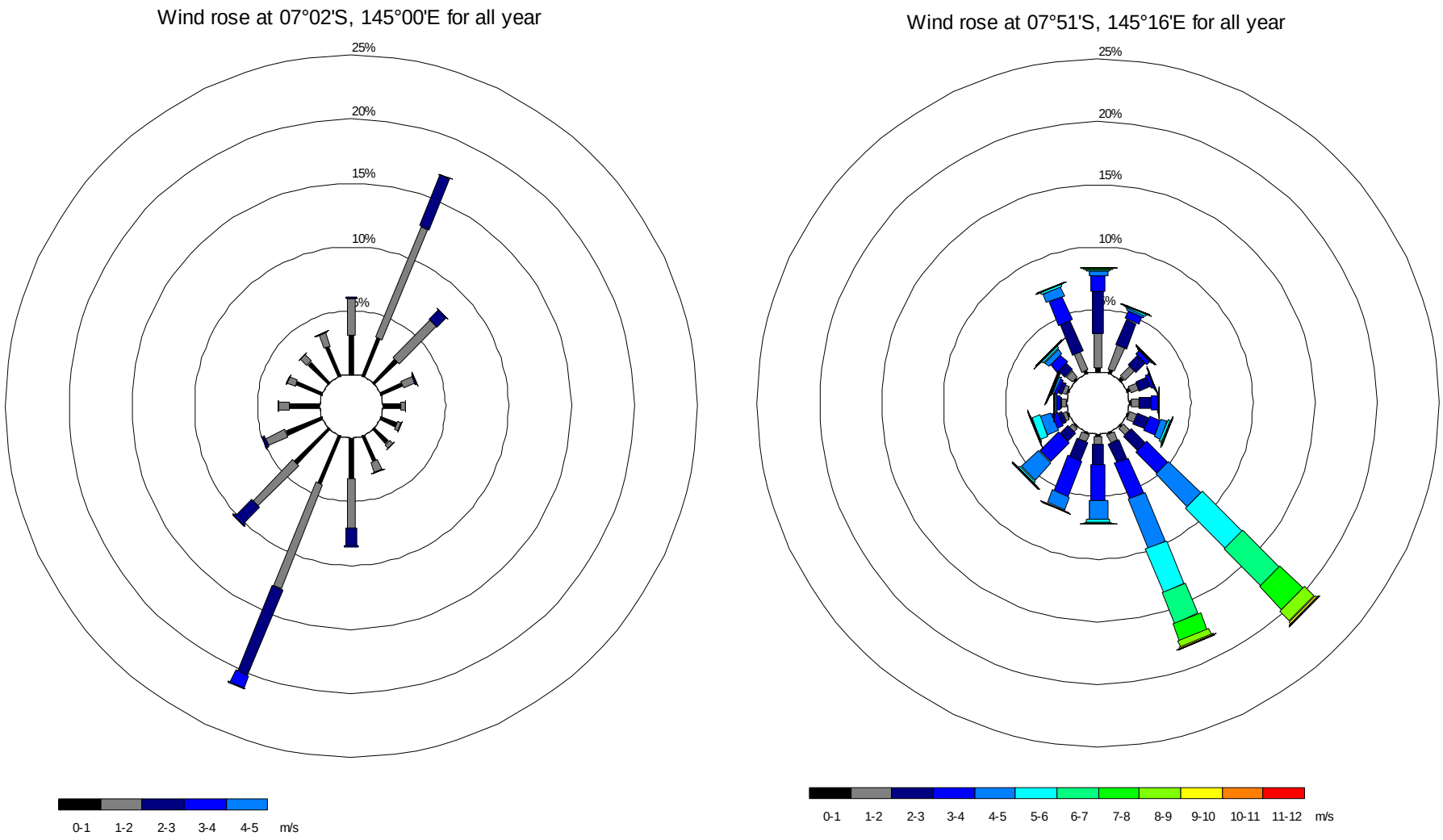


Figure 6-4 Wind Roses for Study Area Locations: PRL-15 well pads (left) and Orokolo Bay (right)

These wind roses demonstrate the temporal and spatial differences in ambient wind conditions in the study area. When comparing between seasons at Herd Base, it can be seen that both north-easterly and south-westerly winds prevail throughout the year, with winds from other directions making up only a small part of the total for each month. The lack of significant change across the seasons at Herd Base is reflective of the low-level convergence that extends through this area, discussed further in Section 6.3.3.

The PRL-15 well pads have similar wind conditions to Herd Base. By contrast, Orokolo Bay has a significantly different wind pattern and appears to be much more heavily influenced by the southeast trade winds season. Winds in this area reach much higher velocities (up to 12 m/s) and are predominantly from the southeast.

This contrast is also shown in Table 6-1. This shows ambient wind statistics, based on modeled data produced by BMT ARGOSS (2015a; 2015b), presented as minimum (min), mean, maximum (max), standard deviation (STD) and ambient extreme wind conditions for Herd Base, the PRL-15 well pads and Orokolo Bay, averaged for the year.

Table 6-1 Annual Ambient Wind Statistics (BMT ARGOSS, 2015a; 2015b)

Location	Overall wind speed (m/s)				Average extremes in wind speed (m/s)	
	Min	Mean	Max	STD	Min	Max
Herd Base	0.00	1.58	6.67	0.87	0.02	4.71
PRL-15 well pads	0.00	1.29	4.83	0.70	0.01	3.84
Orokolo Bay	0.01	3.78	11.72	1.84	0.07	10.69

In terms of extreme events, BMT ARGOSS (2015a; 2015b) indicate the following:

- Within PRL-15 (well pads and Herd Base) the greatest wind speeds for extreme events are the omnidirectional (i.e. coming from all directions) and the south/southwest winds, although winds from the north and northwest at Herd Base also have high wind speeds. These winds speeds are still less than 7 m/s, suggesting an environment that is fairly sheltered during extreme events.
- At Orokolo Bay, the strongest winds associated with extreme events are south-easterlies, southerlies, north-westerlies, and omnidirectional winds. These reach speeds greater than 12 m/s.

As shown in Figure 6-5, significant storm events (i.e. associated with cyclonic low pressure systems) do not regularly occur in the Gulf of Papua or make landfall along the coastline.

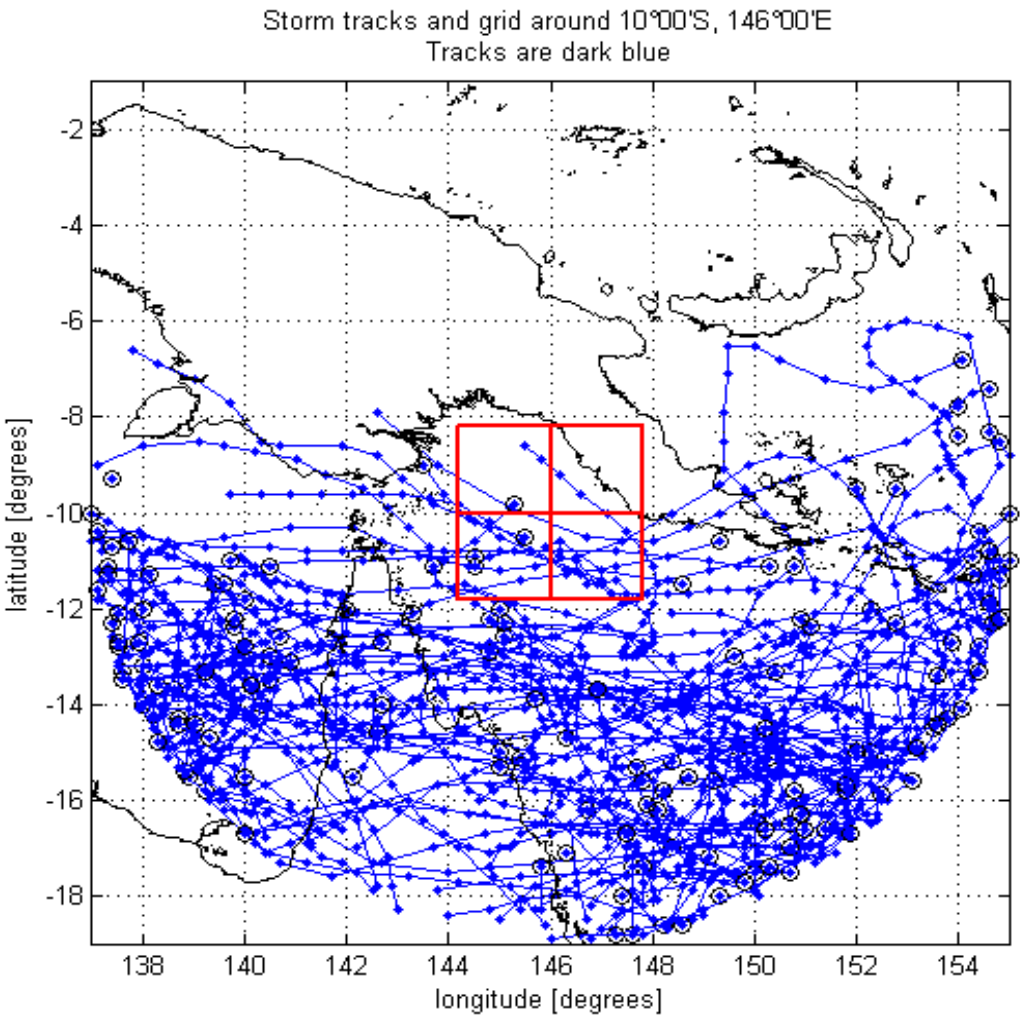


Figure 6-5 Storm Tracks and Grids (BMT ARGOSS, 2015a)

6.3.2 Temperature and Humidity

Evesson (1983) notes that yearly ranges of temperature are mostly insignificant when compared to diurnal ranges. Figure 6-6 represents a plot of minimum and maximum temperatures against elevation for the entire Purari River catchment. This plot indicates a range of minima of approximately 11.6ºC to 22.8ºC and maxima of 22.5ºC to 30ºC. While temperatures in areas downstream of Hathor Gorge (elevation <150 m) would be on the higher end of this spectrum, modeled temperature data reported by BMT ARGOSS (2015a) indicates average maximum temperatures within PRL-15 that are higher again than this range. This is also the case at Orokolo Bay (BMT ARGOSS, 2015b). This is shown in Table 6-2.

Despite these differences, this distribution of temperatures is consistent with the pattern noted by Evesson (1983) of increasing temperature with lower elevation. The cooler temperature at Orokolo Bay is indicative of sea breeze effects causing maximum temperatures to be lower than otherwise indicated by the temperature-elevation relationship.

Table 6-2 contrasts modeled temperature data from BMT ARGOSS with data provided in McAlpine *et al.* (1983) for stations in the upper catchment, and by Ruxton *et al.* 1969 at Kerema. A review of the data shows the following patterns for the catchment which are considered applicable to PRL-15 and the area downstream:

- Mean annual temperatures throughout the year do not fluctuate dramatically, with 1 to 2.5ºC of variation between months.
- June to September are the coolest months of the year.
- There is more variability in extreme minimum temperatures throughout the year than for extreme maximum temperature.

The mean annual humidity for the study area is greater than 80%, with humidity of 100% (or more) occurring in every month through the year. Humidity is highest during the southeast trade wind season (i.e. May to September) and is higher along the coast (Orokolo Bay) than in PRL-15 (well pads and Herd Base) (BMT ARGOSS, 2015a; 2015b).

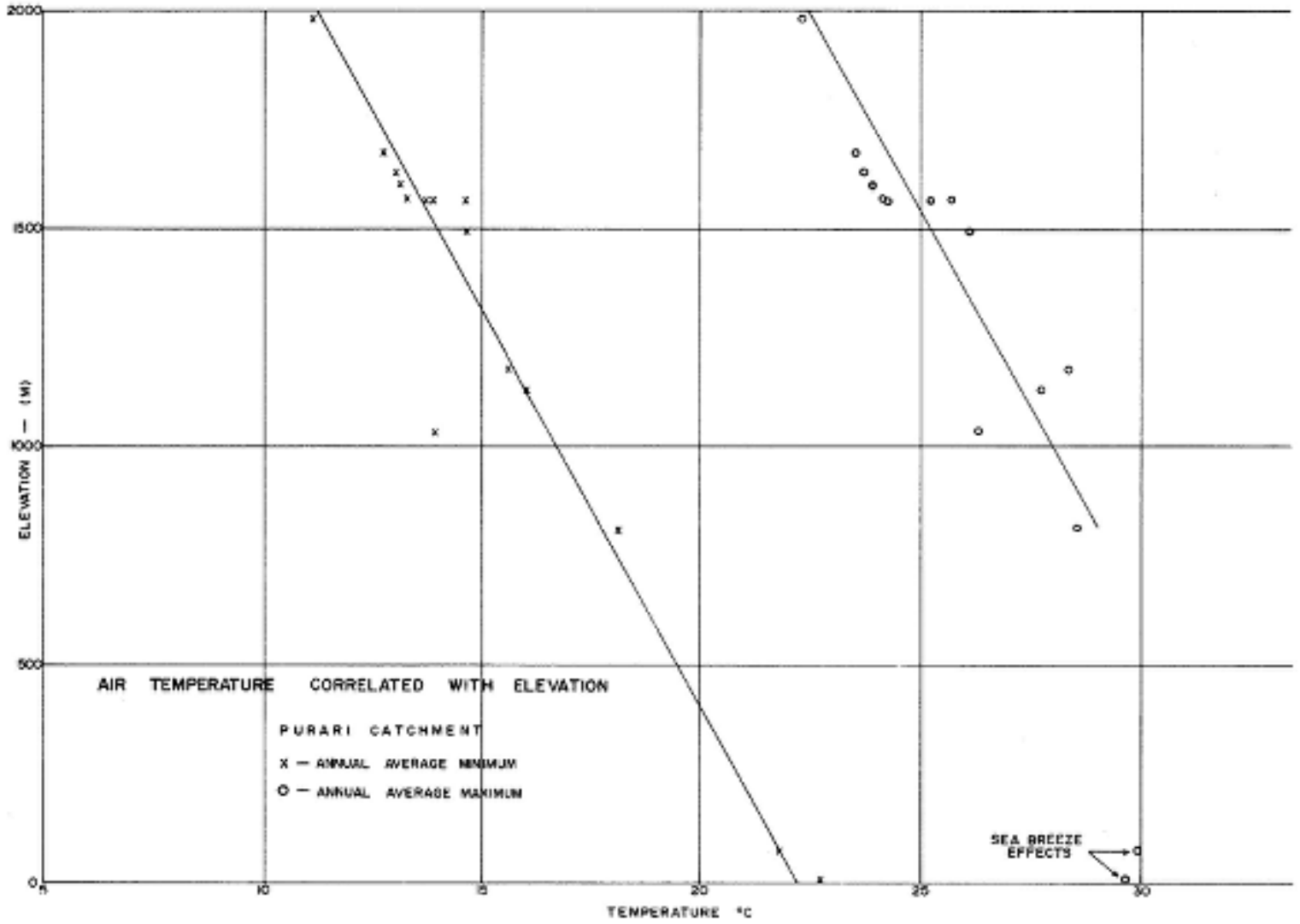


Figure 6-6 Elevation-Temperature Relationship for the Purari River Catchment

Table 6-2 Mean Monthly, Annual and Extreme Temperature Characteristics for Purari River Catchment and Gulf of Papua Coastline Stations (reproduced from BMT ARGOSS, 2015a and 2015b, McAlpine *et al.* 1983 and Ruxton *et al.* 1969)

Station name	Temperature (ºC)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
PRL-15 well pads (BMT ARGOSS, 2015a)	Extreme maximum	40.07	39.12	38.53	37.32	35.51	35.84	35.11	39.48	40.02	39.64	39.16	39.86	40.07
	Mean maximum	-	-	-	-	-	-	-	-	-	-	-	-	--
	Mean	25.84	25.52	25.33	25.27	25.01	24.62	24.02	24.12	24.92	25.38	25.77	25.77	25.13
	Mean minimum	-	-	-	-	-	-	-	-	-	-	-	-	--
	Extreme minimum	16.81	16.55	15.52	15.38	14.74	14,67	14.46	13.09	15.06	12.10	13.81	16.18	12.0
Herd Base (BMT ARGOSS, 2015a)	Extreme maximum	37.64	35.85	35.61	35.19	34.98	34.32	34.82	39.19	38.16	38.56	38.90	37.72	39.19
	Mean maximum	-	-	-	-	-	-	-	-	-	-	-	-	--
	Mean	25.47	25.07	24.92	24.97	24.72	24.33	23.74	23.87	24.72	25.20	25.57	25.49	24.84
	Mean minimum	-	-	-	-	-	-	-	-	-	-	-	-	--
	Extreme minimum	16.34	17.30	16.24	16.57	15.66	15.05	15.07	13.94	15.02	14.90	14.63	16.31	13.94
Orokolo Bay (BMT ARGOSS, 2015b)	Extreme maximum	35.53	33.95	36.45	32.49	31.43	30.29	29.36	30.10	30.47	31.14	32.35	33.86	36.45
	Mean maximum	-	-	-	-	-	-	-	-	-	-	-	-	--
	Mean	28.63	28.49	28.23	27.89	27.53	26.84	26.35	25.89	26.23	26.74	27.43	28.04	7.35
	Mean minimum	-	-	-	-	-	-	-	-	-	-	-	-	--
	Extreme minimum	23.27	23.73	21.94	21.72	21.58	21.78	20.85	18.98	21.28	20.45	21.33	20.66	18.98
Goroka A/S Station No. 200197 1,565 m elevation (McAlpine *et al.* 1983)	Extreme maximum	30.6	29.8	29.4	28.7	30.0	28.9	29.7	29.0	29.4	29.6	30.0	28.3	30.6
	Mean maximum	25.9	25.7	25.6	25.8	26.0	25.2	24.8	25.3	25.7	25.8	26.3	25.8	25.7
	Mean	20.6	20.5	20.5	20.5	20.5	19.6	19.3	19.6	20.0	20.1	20.3	20.5	20.1
	Mean minimum	15.2	15.2	15.4	15.2	14.9	14.0	13.8	13.9	14.2	14.3	14.3	15.1	14.6
	Extreme minimum	10.7	10.0	9.9	8.9	10.3	7.2	8.3	7.2	6.2	6.1	8.3	9.1	6.1
Mt Hagen Station No. 200243 1,630 m elevation	Extreme maximum	31.1	28.9	27.8	28.1	29.1	27.8	27.6	27.8	27.9	28.8	28.3º	30.0	30.1
	Mean maximum	24.2	24.4	23.8	23.9	24.3	23.1	22.4	22.7	23.2	23.9	24.3	24.2	23.7
	Mean	18.8	18.9	18.6	18.8	18.9	17.8	17.5	17.7	17.9	18.2	18.5	18.8	18.3
	Mean minimum	13.4	13.3	13.4	13.7	13.4	12.4	12.5	12.7	12.6	12.5	12.7	13.3	13.0

Station name	Temperature (ºC)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
(McAlpine *et al.* 1983)	Extreme minimum	8.3	5.0	5.0	7.2	2.8	4.4	5.6	5.4	1.7	3.9	4.4	4.7	1.7
Kerema Station No. 200051 ~20 m elevation (Ruxton *et al.* 1969)	Extreme maximum	35.0	35.9	34.6	35.4	33.9	32.3	32.2	32.1	31.8	32.6	33.7	34.8	35.9
	Mean maximum	31.1	30.9	30.9	30.2	29.6	28.4	27.7	27.6	28.1	29.3	30.4	31.1	29.6
	Mean	27.1	27.1	27.0	26.4	26.1	25.6	25.1	24.8	25.3	26.0	26.6	27.0	26.2
	Mean minimum	23.2	23.2	23.1	22.7	22.6	22.8	22.4	22.1	22.4	22.7	22.8	22.9	22.7
	Extreme minimum	20.6	20.6	16.3	14.4	14.4	19.9	18.6	16.3	19.3	17.8	19.4	19.9	14.4

6.3.3 Rainfall

The Purari River catchment is topographically diverse, ranging from sea level to over 4,500 m above sea level at its highest point at Mt Wilhelm on the Bismarck Range. The majority of the highland valleys in the mid to upper reaches of the catchment occur around 1,000 m above sea level (McAlpine *et al.*, 1983). The topography of the catchment forms barriers to wind movement, inhibiting winds from reaching much of the upper catchment during both southeast trade winds and northwest monsoon seasons (Figure 6-7 and Figure 6-8).

This topographical diversity is a key driver of spatial variability in rainfall in the Purari River catchment, with most rainfall being associated with convergence caused by topographical features (Evesson, 1983). At the edge of the inland southern fold mountains in the south-eastern portion of the catchment, the average annual rainfall is approximately 7,000 to 8,000 mm and decreases to approximately 2,000 to 3,000 mm in the north-western portion of the catchment (Evesson, 1983).

In contrast to the effect of topography, however, rainfall in the Purari River catchment between Wabo and the top of the delta is driven primarily by a low level convergence. This brings high levels of rain throughout the year, with significantly higher rainfall during the southeast trade wind season (May to October) than during the northwest monsoon (December to March). As shown in Figure 6-9, this represents a reverse of the rainfall patterns experienced in other parts of the catchment.

This reverse seasonality at Wabo is confirmed by rainfall data from climatic tables published by McAlpine *et al.* (1983). This data is reproduced in Table 6-3 and shows that rainfall levels at Wabo are significantly higher than locations in the upper parts of the Purari River catchment and other locations near the coast (i.e. Kikori and Kerema). Evesson (1983) notes that mean annual rainfall for the entire Purari River catchment is 3,500 mm, in contrast to the 8,900 mm experienced at Wabo. Of this rainfall, approximately 70% occurs during the southeast trade wind seasons (Evesson, 1983; Pickup and Chewings, 1983).

In contrast, modeled data produced by BMT ARGOSS (2015a; 2015b) for PRL-15 well pads, Herd Base and Orokolo Bay does not appear to follow this pattern, showing higher rainfall during the northwest monsoon (Table 6-4). This is likely as a result of modeled data showing wider regional patterns, thereby not accounting for the convergence occurring at PRL-15. The results from this modeling are also much lower than actual rain gauging in similar areas. The BMT ARGOSS modeled data was developed to inform air dispersion modeling rather than hydrological/catchment modeling. It has not been used for hydrologic modeling purposes as it does not provide measured long-term rainfall-runoff and streamflow information necessary for model calibration/validation and as stated above it provided lower rainfall estimates than that of the gauges in the area. This could lead to under estimating flow and flooding extents for the corresponding flood events.

The low level convergence that draws rain to Wabo and the Purari River downstream also occurs over the Pie and Era river catchments. As a result, a similar temporal distribution in rainfall is expected at these catchments. By contrast, rainfall patterns at the Aure River reported by Pickup and Chewings (1983) reflect those for the rest of the Purari River catchment, i.e. higher rainfall in northwest monsoon season and lower in the southeast trade wind season. This is expected to be the result of topographical barriers (as shown in Figure 6-7) preventing southeast trade winds (carrying rain) from reaching much of the catchment.

Rainfall patterns are not greatly affected by cyclones, as the study area is located north of the main cyclone belt (Evesson, 1983).

6.3.3.1 The El Niño Southern Oscillation (ENSO) Phenomenon

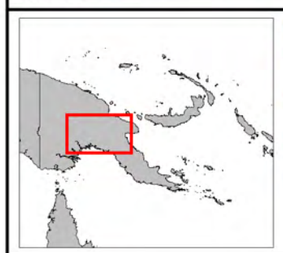
The El Niño Southern Oscillation (ENSO) phenomenon is a very important influence on high and low rainfall extremes in Papua New Guinea (Bourke and Harwood, 2009). Year-to-year variability in rainfall is high in Papua New Guinea, with the wettest years receiving up to three times the rainfall of the driest years (ABM/CSIRO, 2011). The El Niño-Southern Oscillation (ENSO) drives much of this variability. The Southern Oscillation is a global phenomenon in which the temperature of the sea, the air pressure over the sea, and the circulation of air across the oceans move in unison, from one extreme to another. Generally, El Niño years are drier than average while La Niña years are wetter than average. Another impact of El Niño is a late start to the monsoon season.

The Southern Oscillation has been studied over the last 140 years using the air pressure at sea level measured at Tahiti in the eastern Pacific and Darwin in the western Pacific. The difference between the pressure in Tahiti and Darwin has been standardized in to the Southern Oscillation Index (SOI). An ENSO event occurs when the pressure in Darwin is higher than in Tahiti, with sustained negative SOI values below −8 typically indicating an El Niño event. Between 1876 and 2005 there were 25 years when the SOI was less than –10 in April and October. In 11 of these 25 years, official reports, newspapers and oral histories describe the occurrence of widespread droughts. Droughts were reported to be very serious in four of these 11 years (1902, 1914, 1941 and 1997) (Bourke and Harwood, 2009).

As there is no consistency in projections of future ENSO activity, it is not possible to determine whether inter-annual variability in rainfall will change in the future (ABM/CSIRO, 2011).

Madang
Mendi
Goroka
Wabo
Kikori
Kerema

Image courtesy of NASA Earthstar Geographics SIO © 2017 Microsoft Corporation



LEGEND

- PRL-15 Boundary
- Purari River Catchment above Wabo
- Waterways

Wind and Topographic Data

- Winds at 900 - 1500m Altitude
- Exposed Slopes
- Minor Barrier
- Major Barrier

* Wind & Topographic Data digitised from hard copy map (Evesson, 1983)

Title:

Interaction Between Winds and Topographic Features during Southwest Trade Wind Season (Reproduced from Evesson, 1983)

Figure: 6-7

Rev: A

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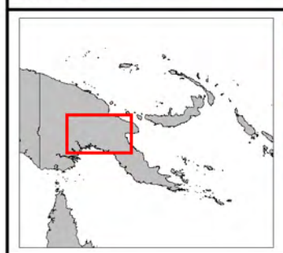
Approx. Scale

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Madang
Mendi
Goroka
Wabo
Kikori
Kerema

Image courtesy of NASA Earthstar Geographics SIO © 2017 Microsoft Corporation



LEGEND

PRL-15 Boundary

Purari River Catchment above Wabo

Waterways

Wind and Topographic Data

Winds at 900 - 1500m Altitude

Exposed Slopes

Minor Barrier

Major Barrier

* Wind & Topographic Data digitised from hard copy map (Evesson, 1983)

Title:

Interaction Between Winds and Topographic Features during Northwest Monsoon Season (Reproduced from Evesson, 1983)

Figure: 6-8

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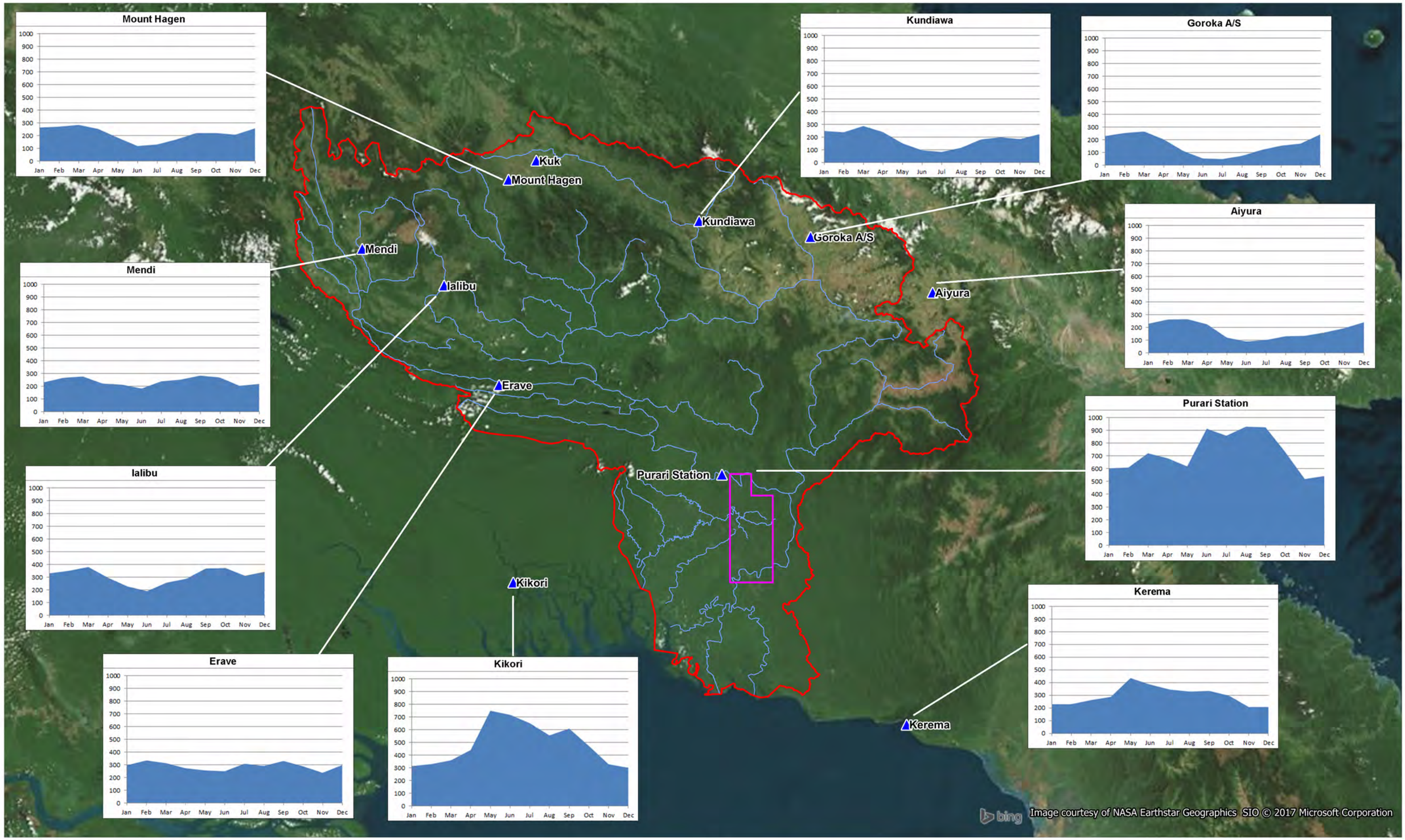
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LEGEND

- PRL-15 Boundary
- Purari River Catchment
- Waterways
- Rainfall/Streamflow Station

Title:

Rainfall Distribution Patterns for the Purari River Catchment and Other Areas

Figure: 6-9

Rev: A

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Table 6-3 Mean Monthly Rainfall Values (mm) for Purari River Catchment and Gulf of Papua Coastline Stations (reproduced from McAlpine *et al.* 1983)

Station	No.	Years of record	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Purari River catchment															
Aiyura	200003	29 years	230	263	265	225	121	90	102	131	135	161	195	241	2,156
Erave	200188	14 years	297	335	314	274	257	250	309	292	331	289	238	299	3,405
Goroka A/S	200197	19 years	230	254	266	204	113	54	49	74	121	154	171	243	1,921
Ialibu	200314	13 years	331	351	381	297	228	191	258	288	369	373	312	343	3,752
Kundiawa	200182	13 years	249	239	288	241	152	97	84	117	182	200	185	224	2,249
Mendi	200399	13 years	231	267	277	222	213	183	239	253	284	269	204	219	2,800
Mt Hagen	200243	20 years	264	271	285	253	184	119	131	171	221	221	208	258	2,586
Wabo Dam Site (Purari station)	200673 (712400)	2 years	603	609	721	682	618	914	859	930	925	732	519	542	8,700
Gulf of Papua coastline															
Kerema	200051	44 years	231	232	264	289	437	386	347	331	336	299	209	209	3,612
Kikori	200054	43 years	314	330	360	441	750	718	652	556	610	473	329	301	5,772

Table 6-4 Mean Monthly Rainfall Values (mm) for PRL-15 Well Pads, Herd Base and Orokolo Bay (derived from BMT ARGOSS, 2015a and 2015b)

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
PRL-15 well pads	173	166	187	238	166	122	94	108	166	216	173	158	1,966
Herd Base	230	238	230	245	173	130	94	101	108	166	180	180	2,074
Orokolo Bay	99	83	97	122	243	246	153	72	108	117	120	61	1,518

6.3.4 Evaporation

Evesson (1983) identifies a likely annual evaporation rate at Wabo (elevation ~40 m) of 1,200 mm. This is derived from an extrapolation by McAlpine (1975) of annual evaporation rates at Kuk (near Mt Hagen, elevation ~1,630 m) in the upper Purari River catchment where there is five years of US Class A pan measurements. The annual evaporation rate at Kuk is 1,599 mm. Table 6-5 reproduces the evaporation data for Kuk, together with data from other stations in the Purari River catchment (published in McAlpine *et al.* 1983). Table 6-5 also includes the annual evaporation rate for Wabo (derived by McAlpine *et al.* 1975) and for Kerema (from Ruxton *et al.* 1969). An indicative distribution of evaporation across the months is not possible for Wabo, however, due to the reversed seasonality at this location comparative to Kuk.

A comparison of the data provided in Table 6-5 and Table 6-3 indicate a weak correlation between rainfall patterns and evaporation, with more evaporation tending to occur in the same months where rainfall levels are high. Table 6-5 also indicates a lower level of evaporation experienced at sites nearer to the coast (i.e. Wabo and Kerema) compared to the upper part of the catchment.

Table 6-5 Evaporation Rates (mm) for Purari River Catchment and Gulf of Papua Coastline Stations* (McAlpine *et al.* 1983; Evesson, 1983; Ruxton *et al.* 1969)

Station name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Purari River catchment													
Kuk	137	123	130	150	124	112	117	136	144	137	140	149	1,599
Aiyura	131	120	136	135	128	119	124	128	151	132	140	137	1,581
Goroka A/S	155	133	152	146	166	134	150	156	177	169	165	163	1,866
Mt Hagen	133	119	127	128	136	111	114	124	143	145	144	144	1,568
Wabo (Purari)	No data available on monthly distribution of evaporation rates												1,200
Gulf of Papua coastline													
Kerema	130	127	122	109	104	102	94	94	91	109	124	142	1,348

*Reproduced from McAlpine *et al.* (1983) and Evesson (1983), with Kerema information from Ruxton *et al.* (1969)

It is noted by Evesson (1983) that the US Class A pan measurements give an overestimate of actual evaporation from a water surface. Evesson has also provided estimates of evaporation by comparison of net rainfall and flow in the Purari River (see Section 6.4) with expected percolation (i.e. groundwater transport) rates. These estimates, combined with expected overestimates associated with US Class A pan measurements, indicate that the results in Table 6-5 should therefore be treated with caution, with evaporation rates at Wabo likely to be closer to 1,000 mm/yr.

6.4 Hydrology

6.4.1 Catchments

The study area spans the following three catchments:

- Purari River catchment (including Urika-Ivo and Wame-Varoi rivers)
- Pie River catchment
- Era River catchment.

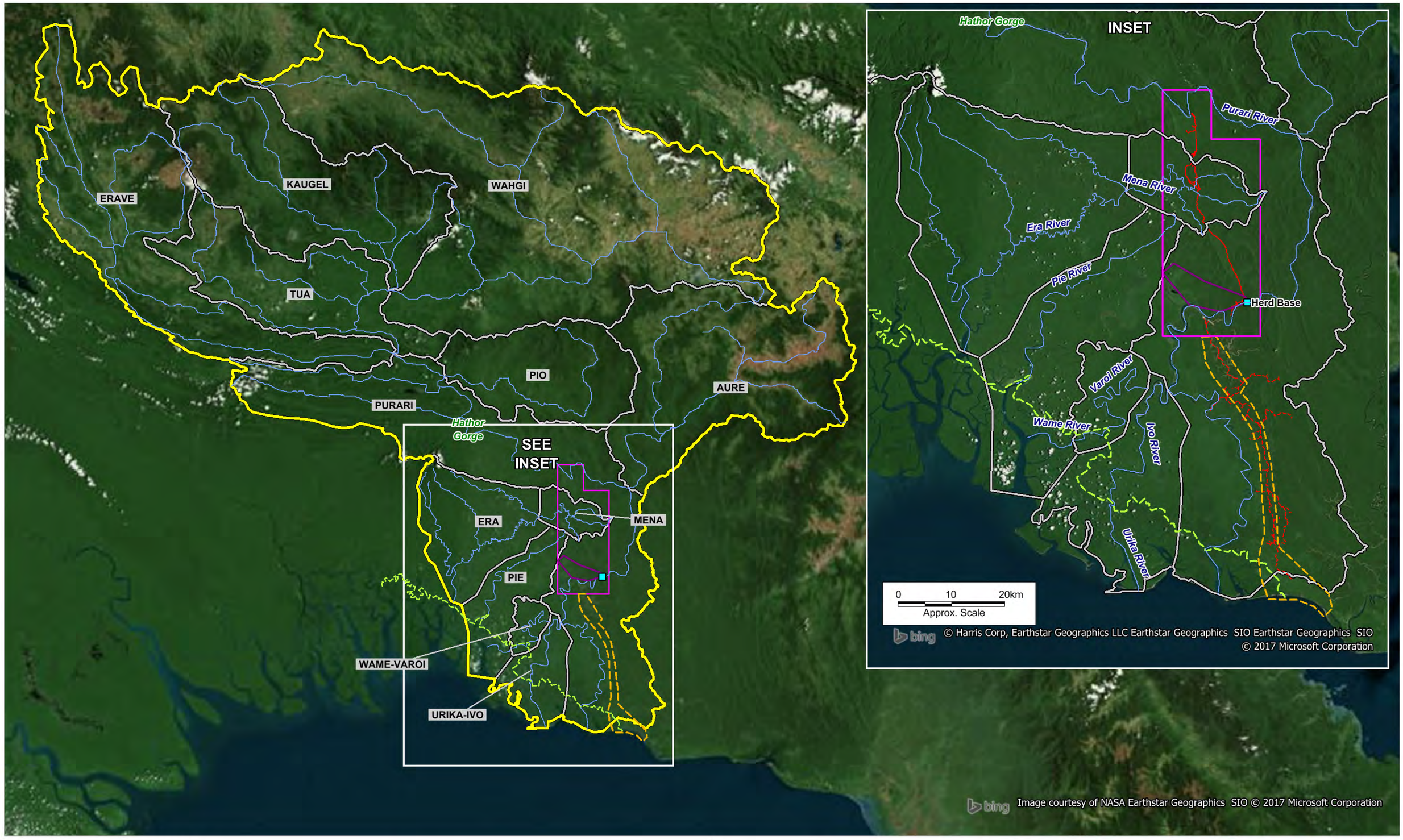
While the hydrology of the Purari River has previously been described, there is comparatively little catchment specific information on the hydrology of the Pie and Era river catchments. However, the broad-scale processes controlling hydrology (i.e. rainfall-runoff) will be consistent among these catchments.

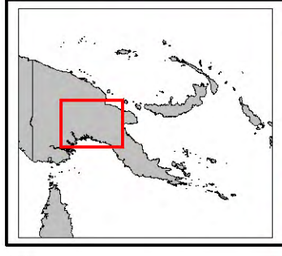
The Purari River is Papua New Guinea's third largest river (by catchment size) with a total catchment area of 33,730 km^2. The Aure River joins the Purari River near the village of Subu, approximately 8 km to the east of PRL-15. Table 6-6 presents a description of the key Purari River catchments as well as the Pie River and Era River catchments, derived from the DEM. The catchments areas and stream lengths in Table 6-6 are the total upstream catchment and the entire main channel length for that sub-catchment.

These catchments are shown in Figure 6-10.

Table 6-6 Catchment Overview

Basin	Catchment	Approximate catchment dimensions	
		Area	Length
Purari River	Purari (main river)	33,730 km^2	616 km
	Erave	5,330 km^2	222 km
	Kaugel	4,000 km^2	130 km
	Aure	4,340 km^2	150 km
	Tua	16,720 km^2	315 km
	Pio	2,000 km^2	115 km
	Wahgi	10,360 km^2	267 km
	Wame-Varoi	210 km^2	62 km
	Urika-Ivo	620 km^2	62 km
Pie River	Pie	910 km^2	82 km
Era River	Era	1,750 km^2	144 km





LEGEND

- Study Area
- Catchment Boundaries
- Waterways
- PRL-15 boundary
- CPF area
- Herd Base
- Narrowed Onshore Pipeline Corridor
- Indicative Estuarine Boundary
- Existing Roads
- Existing Tracks

Title:
Catchment Overview

Figure: 6-10

Rev: A

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Scale - Main Map

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6.4.2 Rainfall Runoff and Streamflow

6.4.2.1 Previous Assessments (Pickup and Chewings, 1983)

Estimates for annual rainfall runoff in the study area are not well defined but are in the order of 2,000 to 4,000 mm across the Purari catchment (Pickup and Chewings, 1983). By comparison, the average annual runoff for Papua New Guinea is 2,100 mm (Bonell *et al.* 2005).

The rainfall runoff coefficient at Wabo, in the upstream part of the study area, is expected to be greater than 0.7 (Pickup and Chewings, 1983). Seasonal distribution of runoff across the entire catchment is shown in Figure 6-9. This indicates that most runoff occurs in the early months of the year when soils are saturated from rainfalls (Pickup and Chewings, 1983).

Mean daily discharge from the Purari River here is approximately 2,360 m^3/s with an annual maximum of between 6,290 m^3/s and 10,405 m^3/s (for the period 1961 to 1978) and an average minimum of 1,920 m^3/s (Pickup and Chewings, 1983). The mean daily discharge from the Aure River is 307 m^3/s (Pickup and Chewings, 1983).

A comparison between annual river flow and rainfall rates for the Purari River catchment in equivalent rainfall units identifies a difference of ~800 mm (i.e. ~3,500 mm rainfall minus ~2,700 mm river flow). As annual evaporation is expected to be approximately 1,000 mm (see Section 6.3.4) there is an additional 200 mm of flow into the Purari River not directly attributable to rainfall; Evesson (1983) indicates that this is likely to represent subsurface percolation of water from the Strickland River catchment to the Purari River catchment (i.e. groundwater flow).

6.4.2.2 Present Study

Streamflow assessments undertaken as part of the present study are based on catchment modeling using the Source Catchments framework. Source Catchments is used for modeling river systems and typically focuses on the balance and volume of water within these systems. As such, Source Catchments commonly outputs data in a volume per unit time, such as ML/day (with 86.4 ML/day equivalent to 1 m^3/s). The streamflow assessments present estimates of streamflow parameters (i.e. volume, variation, baseflow and duration) for six reporting locations:

(1) Location 1 – representative of Purari River flow and loads upstream of PRL-15 at sub-catchment (SC) 24

(2) Location 2 – representative of the local flows and loads at Hou Creek Base located along Hou Creek in sub-catchment 34

(3) Location 3 – representative of the local flows and loads along Boa Creek in sub-catchment 36

(4) Location 4 – representative of the local flows and loads of the Mena River before its confluence with the Era River in sub-catchment 37

(5) Location 5 – representative of the local flows and loads of Kuku Creek at Herd Base in sub-catchment 39

(6) Location 6 – representative of Purari River flow and loads downstream of PRL-15 at sub-catchment 42.

These locations are within sub-catchments derived from the Source Catchments modeling software for the purposes of the sediment load assessment (see further Section 6.6.2). Reporting locations and sub-catchments are shown in Figure 6-11.

NOTE: Sub-catchments used for streamflow assessments differ slightly from those utilized for hydrology and hydraulic assessments described in Section 6.4.3.2 due to the nature of the modeling software used and the intent of the assessments.

Modeled streamflow along the Purari River and its tributaries in the vicinity of the PRL-15 site (see Figure 6-12) demonstrates obvious seasonality corresponding to inter-annual rainfall variations. Mean monthly streamflows across the simulated duration (March 2000 to December 2015) show the months of May, June and July as having the greatest streamflow for all three reporting locations. The period May to July falls within the south-easterly trade wind season extending from May to October each year, concurrent with the findings of Pickup and Chewings (1983) for the greatest amount of rainfall experienced downstream of Wabo. November and December had the lowest mean monthly streamflows across the modeled duration, likely to be due to drier conditions downstream of Wabo during this period.

Baseflow

The baseflow contribution to streamflow is used to assess low-flow characteristics of rivers using the mean daily streamflow. The baseflow index (BFI) of a system represents the ratio of long-term baseflow to the total streamflow (Gustard *et al*. 1992). Here, baseflow represents low flows within a river system between rainfall events, i.e.; that is, streamflow sustained during dry weather periods. Based on the catchment modeling undertaken by BMT WBM, the BFI for areas within the study area upstream and downstream of PRL-15 can be summarized as follows:

- Location 1 (SC 24 – Purari River upstream of PRL-15) had a BFI of 0.37 with a mean daily baseflow of 6,478 ML/day (75 m^3/s). The annual BFI across the modeled duration ranged from 0.32 to 0.55.
- Location 2 (SC 34 – Hou Creek) had a BFI of 0.33 with a mean daily baseflow of 34 ML/day (0.4 m^3/s). The annual BFI across the modeled duration ranged from 0.21 to 0.54.
- Location 5 (SC 39 – Kuku Creek) had a BFI of 0.34 with a mean daily baseflow of 20 ML/day (0.2 m^3/s). The annual BFI across the modeled duration ranged from 0.22 to 0.54.
- Location 6 (SC 42 – Purari River downstream of PRL-15) had a BFI of 0.38 with a mean daily baseflow of 8,470 ML/day (98 m^3/s). The annual BFI across the modeled duration ranged from 0.34 to 0.57.

The BFI at each reporting location was generally higher between May to October each year, corresponding to the elevated stream flows during the south-easterly trade wind season from elevated runoff in the catchment.

The similar BFI across all locations indicates that for most of the modeled duration, around one third of the total streamflow is attributed to baseflow along the Purari River and its tributaries, with some months experiencing around half of the total streamflow from baseflow. Additionally, based on modeling results it is apparent that Location 2 and Location 5 (within PRL-15) have a

significantly lower mean daily baseflow when compared to Location 1 and 6, indicating the negligible contribution of these areas to downstream baseflow at a catchment scale.

Total Flow Volumes

The total flow volumes modeled for the Purari River catchment are shown in Figure 6-12 below. The following observations can be made based on the results of this modeling:

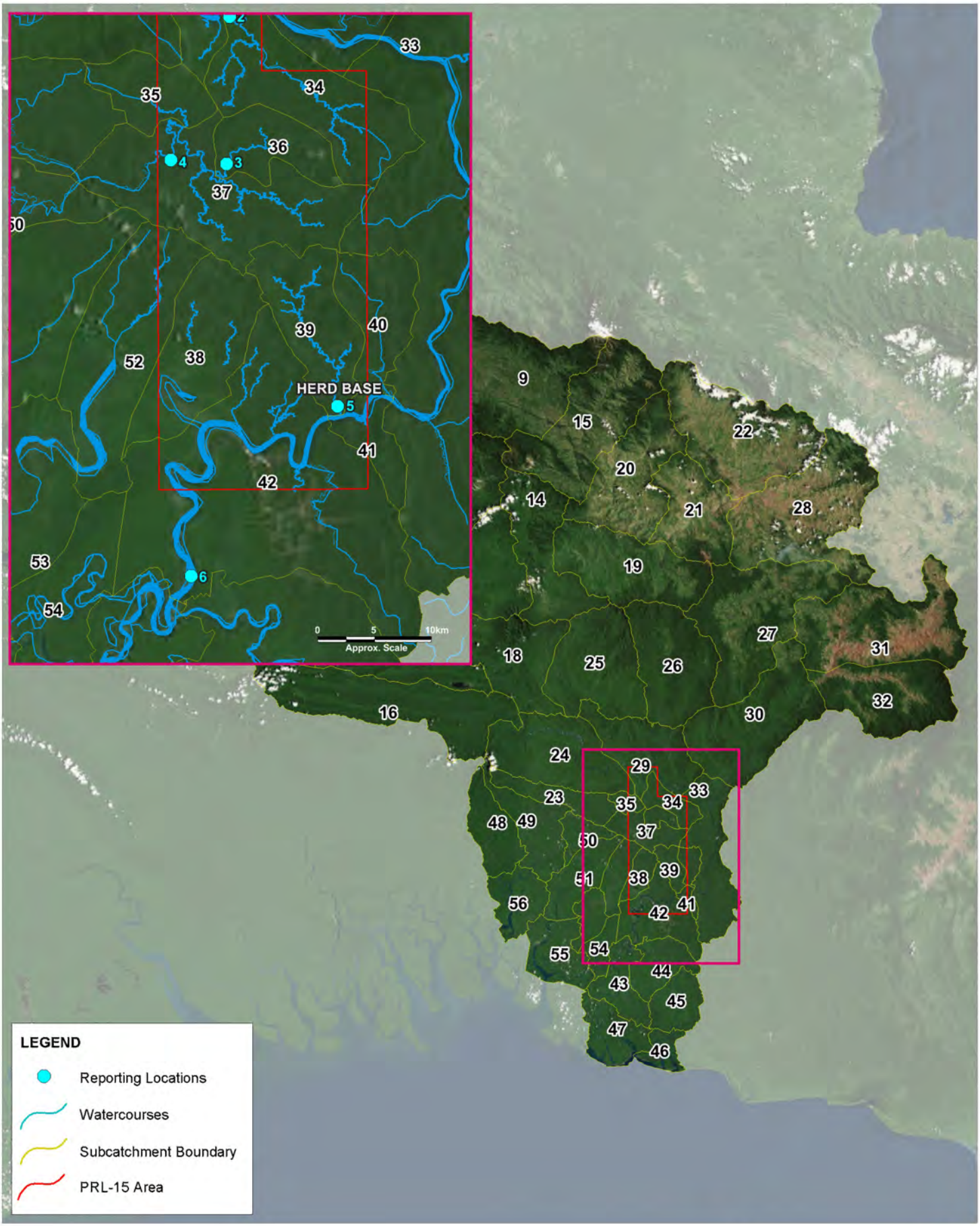
- Location 1 (SC24 – Purari River upstream of PRL-15) has peak flows in excess of 250,000 ML/day during high flow events with a mean daily flow of 17,500 ML/day. These large flows are associated with the large catchment area (30,700 km^2) upstream of this location.
- Location 2 (SC34 – Hou Creek) has flows in excess of 2,000 ML/day during periods of high rainfall and has a mean flow of 100 ML/day.
- Location 3 (SC36 – Boa Creek) has flows in excess of 1,000 ML/day during periods of high rainfall and has a mean flow of 40 ML/day.
- Location 4 (SC37 – Mena River) has flows in excess of 2000 ML/day during periods of high rainfall and has a mean flow of 133 ML/day. This represents an increased mean flow of 1,000 ML/day between locations 3 and 4.
- Location 5 (SC39 – Kuku Creek) has flows in excess of 1500 ML/day during periods of high rainfall and has a mean flow of 58 ML/day.
- Location 6 (SC42 – Purari River downstream of PRL-15) has peak flows in excess of 250,000 ML/day with a mean flow of approximately 22,400 ML/day. This represents an increased mean flow of 5,000 ML/day between locations 1 and 6, contributed primarily by the Aure River.

The sub-catchments within PRL-15 (i.e.; locations 2 and 5) represent approximately 3.3% of the total contribution to mean daily flow volumes between locations 1 and 6, indicating a negligible contribution by PRL-15 to the Purari River catchment.

A summary of the modeled streamflow results is shown in Table 6-7.

Table 6-7 Existing Streamflow at the Selected Report Locations (Sub-catchments)

Reporting Location	Catchment Area (km^2)	Mean Daily Flow (ML/day)	Mean Annual Flow (ML/year)
1	30,700	17,500	6,325,430
2	136	102	36,791
3	53	40	14,389
4	177	133	48,076
5	89	58	20,929
6	32,920	22,400	8,106,615



Title:
Reporting Locations

Figure: 6-11

Rev: A

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Approx. Scale

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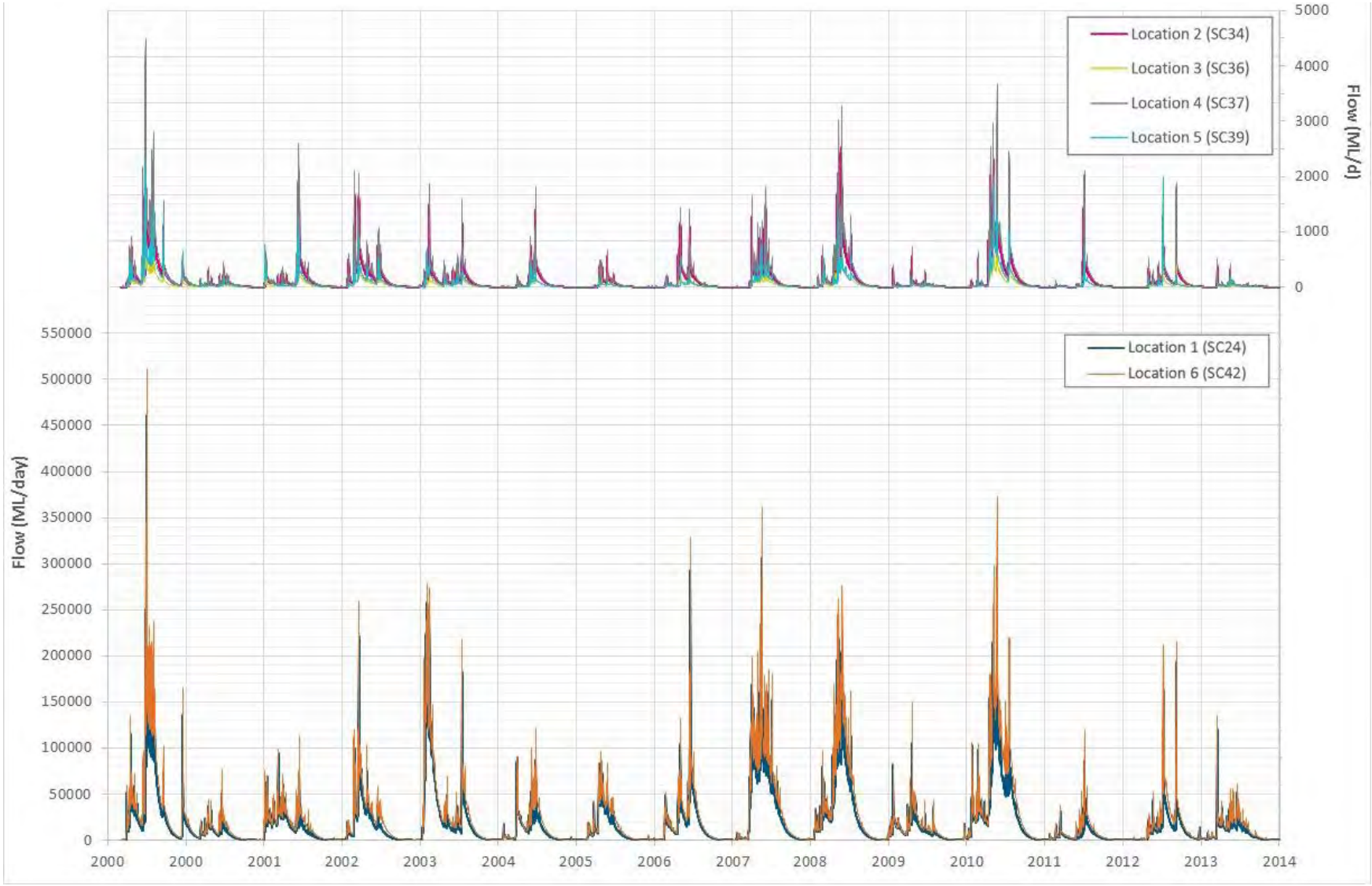


Figure 6-12 Downstream Flow Volume at all Reporting Locations

Flow Duration

Flow duration is a key indicator of streamflow characteristics and was calculated as a percentage of time equaled or exceeded for a range of flow conditions (i.e.; high, moderate and low flow) across key reference locations, as shown in Figure 6-13 and Figure 6-14.

The flow duration for the reference locations is summarized below:

- At Location 1 (Purari River upstream of PRL-15), 95% of the time flows are greater than 150 ML/day (5th percentile flow), 50% of the time flows are greater than 6,500 ML/day (median flow), 10% of the time flows are greater than 45,000 ML/day (90th percentile flow), and 5% of the time flows are close to 80,000 ML/day (95th percentile flow).
- At Location 2 (Hou Creek), 95% of the time flows are less than 1 ML/day (5th percentile flow), 50% of the time flows are greater than 25 ML/day (median flow), 10% of the time flows are greater than 275 ML/day (90th percentile flow) and 5% of the time flows are greater than 450 ML/day (95th percentile flow).
- At Location 5 (Kuku Creek), 95% of the time flows are less than greater than 1 ML/day (5th percentile flow), 50% of the time flows are greater than 15 ML/day (median flow), 10% of the time flows are greater than 150 ML/day (90th percentile flow) and 5% of the time flows are greater than 250 ML/day (95th percentile flow).
- At Location 6 (Purari River downstream of PRL-15), 95% of the time flows are greater than 250 ML/day (5th percentile flow), 50% of the time flows are greater than 10,000 ML/day (median flow), 10% of the time flows are greater than 60,000 ML/day (90th percentile flow), and 5% of the time flows are close to 100,000 ML/day (95th percentile flow).

The modeled data shows that the low flow (5th percentile flow) at locations 2 and 5 (~1 ML/day) is approximately 0.4% of the low flow at Location 1 and 0.7% of the low flow at Location 6. High flows (90th percentile flow) at locations 2 and 5 were greater than 150 ML/day, however, this still represents only approximately 0.3% of the high flows modeled at locations 1 and 6. The large difference between the 90th and 95th percentile flows at all locations suggest the entire system is highly responsive to runoff, particularly as it becomes saturated during prolonged rainfall events.

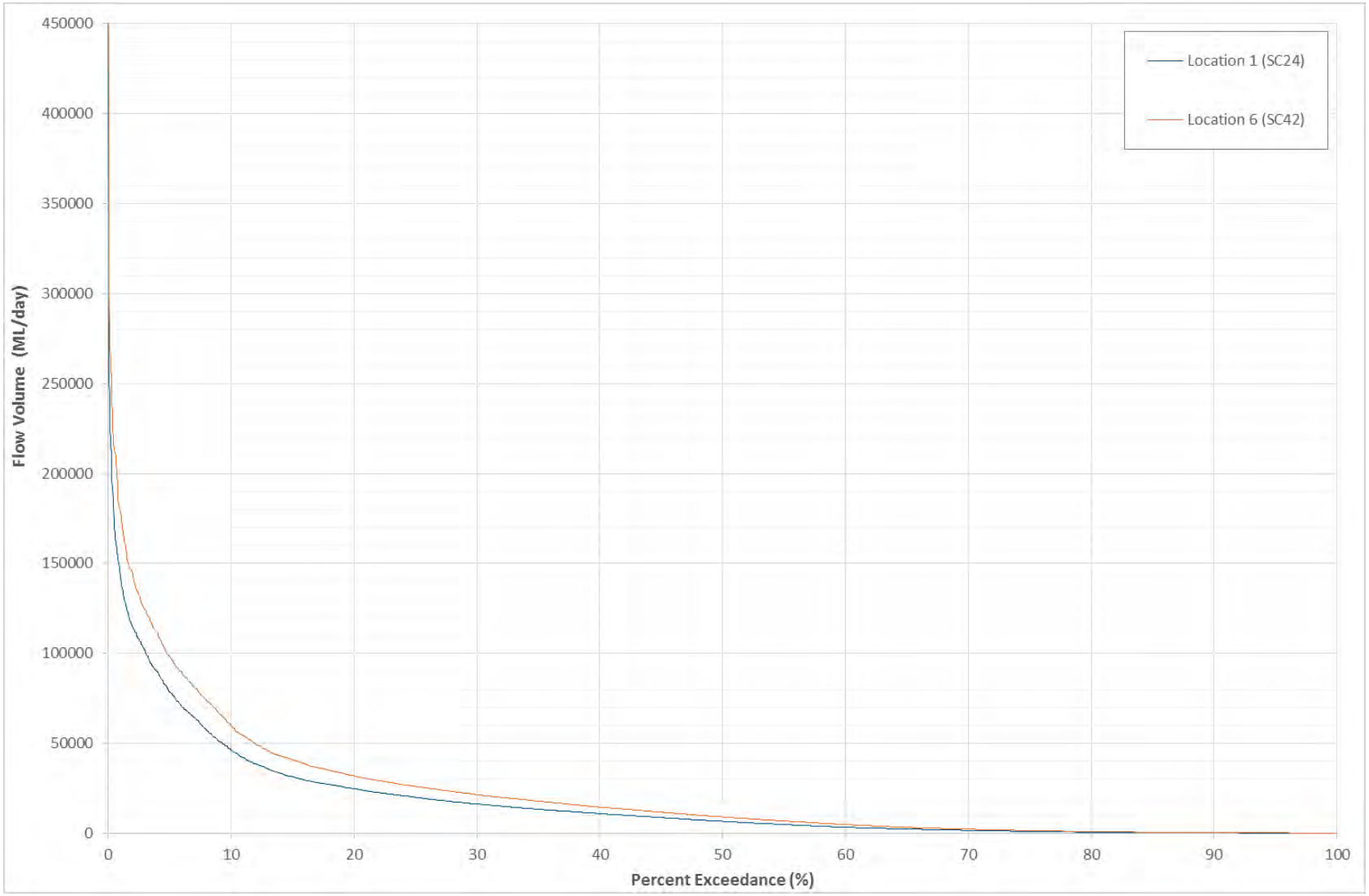


Figure 6-13 Flow Duration Curves at Reporting Locations 1 and 6

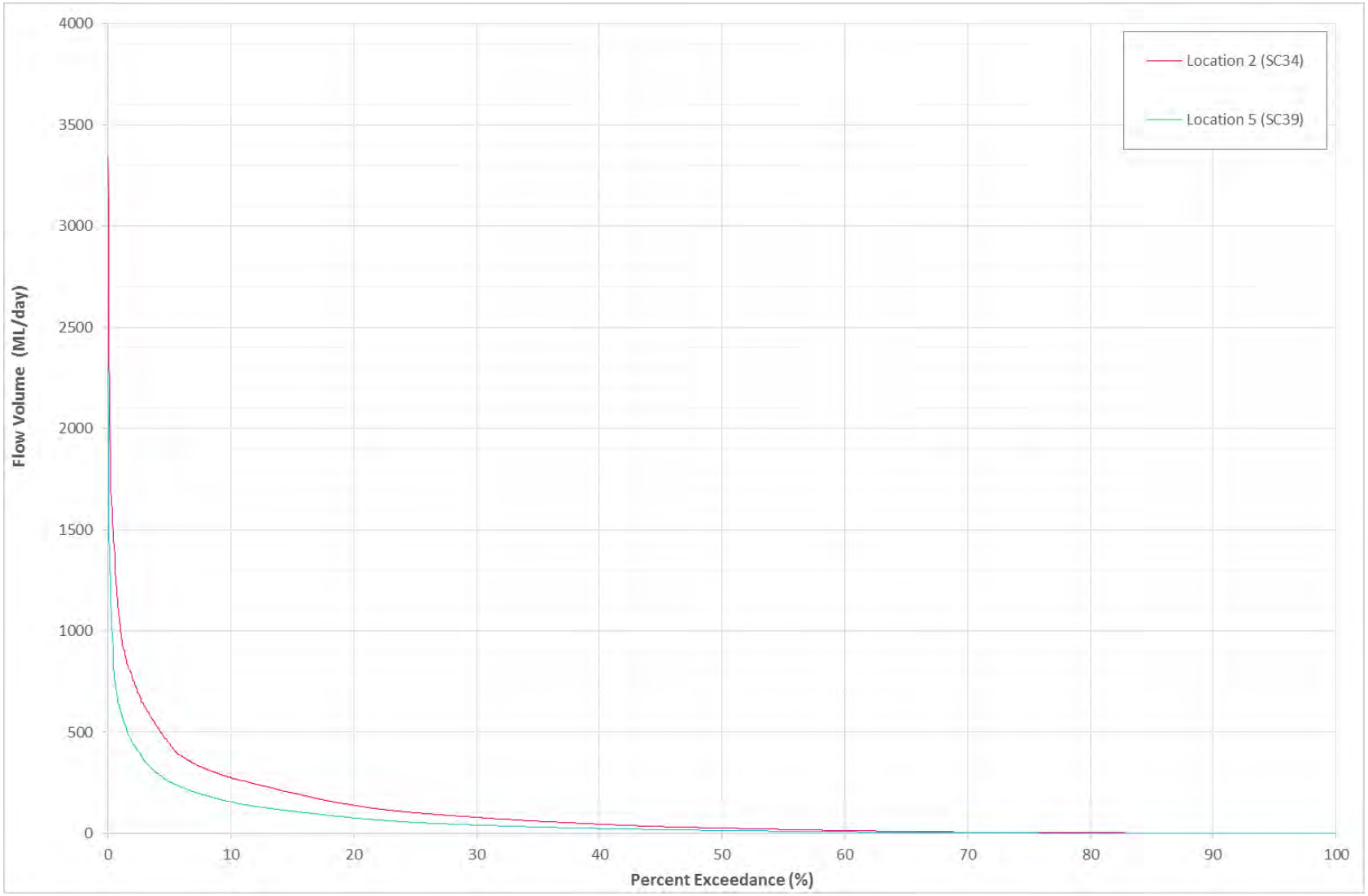


Figure 6-14 Flow Duration Curves at Reporting Locations 2 and 5

6.4.3 Flood Frequency

6.4.3.1 Previous Assessments (Pickup and Chewings, 1983)

Figure 6-15 contains a flood frequency curve for both the Purari and the Aure rivers, based on data from SMEC-NK (1977) and Carter (1980 (cited in Pickup and Chewings, 1983). The data that this curve is based on covers the period 1961 to 1978 (Purari) and 1966 to 1978 (Aure). Based on this data, the following observations regarding flow events are made:

- Flood variability for both rivers across years is low, due in part to the regularity and length of the wet season (which ensures saturation remains high throughout the year and across years).
- The size of floods in the Purari River are quite large comparative to the size of the catchment. Pickup and Chewings (1983) observed that an equivalent flood event (based on the peak discharge to area ratio) is likely to occur in the humid tropical area of northern Australia within a catchment with third of the size of the Purari River catchment. NOTE: The peak discharge to area ratio of floods tends to be higher in smaller catchments.
- While floods can occur throughout the year in both rivers, flood events in the Purari are generally linked to south-easterly weather patterns that occur from June to September. By contrast, flooding in the Aure appears to be dominated by north-westerly patterns in February to March.
- Low flow events can occur at any time of the year but are more directly correlated to seasons than flooding. For both rivers, the lowest flow events tend to occur during the south-easterly season (in the upper Purari River catchment and in the Aure River catchment). This is also the season when floods occur on the Purari River (downstream of Hathor Gorge). The difference is likely due to the reverse seasonality experienced in the lower part of the catchment comparative to the upper catchment: while high rainfall events are more common during the south-easterly trade winds season (leading to flood events) there is a lack of sustained high rainfall events in the Purari River upper catchment at this time, leading to low flow events.

The peak flood and low flow events recorded for the Purari and Aure rivers by SMEC-NK (1977) and Carter (1980) are shown in Table 6-8.

Table 6-8 Peak Flood and Low Flow Events for Purari (1961-1978) and Aure (1966-1978) (Pickup and Chewings, 1983)

River	Mean daily discharge	Maximum daily discharge	Minimum daily discharge
Purari	2,360 m^3/s	6,290 to 10,450 m^3/s	487 m^3/s
Aure	307 m^3/s	1,341 to 2,887 m^3/s	44 m^3/s

A complete set of flow statistics for the Purari and Aure rivers is provided in Appendix B.

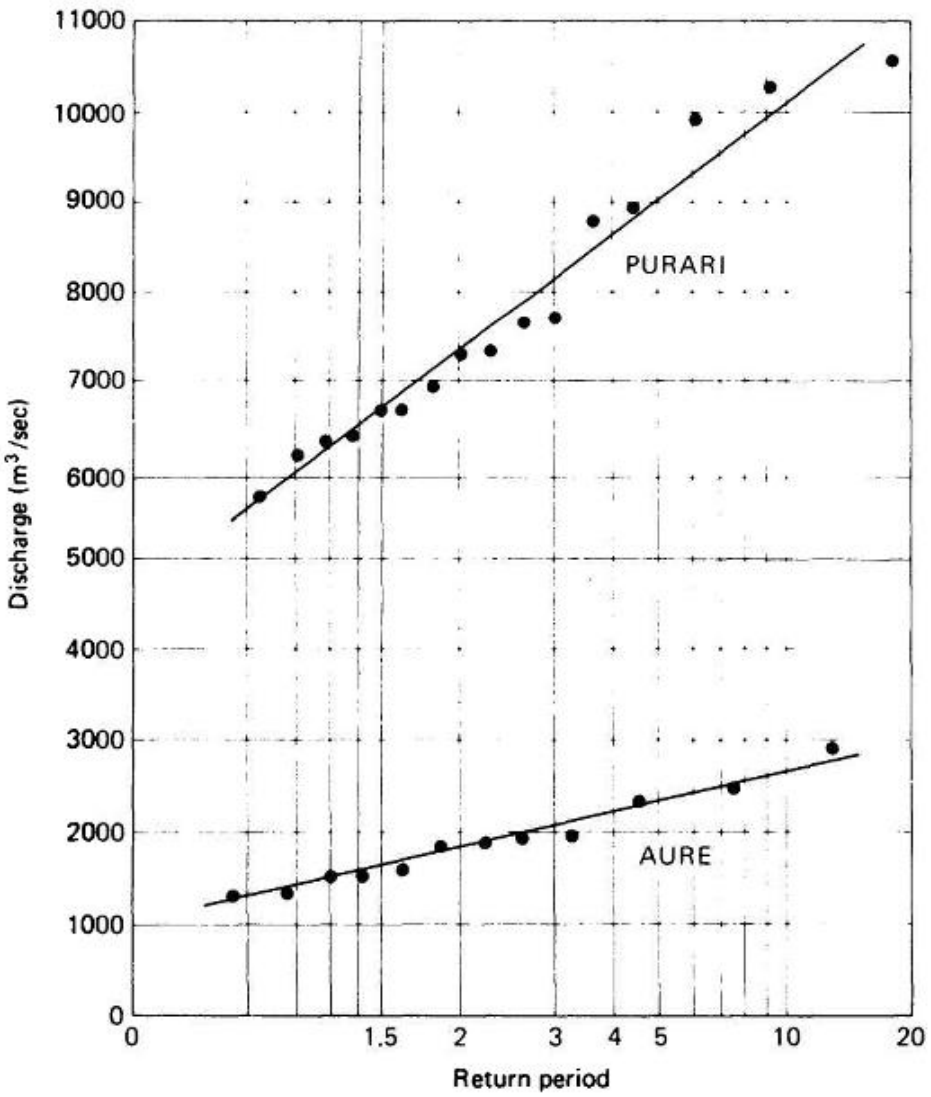


Figure 6-15 Flood Frequency Curve for Purari and Aure Rivers (reproduced from Pickup and Chewings, 1983)

6.4.3.2 Present Study

In order to represent the hydrologic (rainfall-runoff) behavior of the Purari, Pie and Era rivers, these catchments need to be divided into sub-catchments. The software package 'CatchmentSIM' has been used to achieve an appropriate sub-catchment discretization based on SRTM ground elevation data. CatchmentSIM initially derives the stream network and then automates the sub-catchment breakdown based on this network. CatchmentSIM is guided by the user identifying focus areas with the sub-catchment delineation focused on these locations. Following the use of CatchmentSIM, the sub-catchments are visually assessed to determine suitability and manual changes made to the sub-catchment boundaries as necessary.

Of the eighty (80) sub-catchments presented in Figure 6-16, twenty (20) of these sub-catchments are considered to be most relevant to the Project as they may potentially 'host' trunkline and

onshore export pipeline corridors and other relevant Project activities. The 20 sub-catchments relevant to this assessment are listed below and are shown in Figure 6-16.

- Era River catchment – Sub-catchments 2, 3, 4, 5
- Purari River catchment – Sub-catchments 1, 8 to 13, 15, 17 to 27.

No target sub-catchments have been identified in the Pie River catchment as waterway-crossing infrastructure is not anticipated for tributaries in this area.

The relationship between these sub-catchments and the TUFLOW hydraulic models are discussed in Section 6.5.

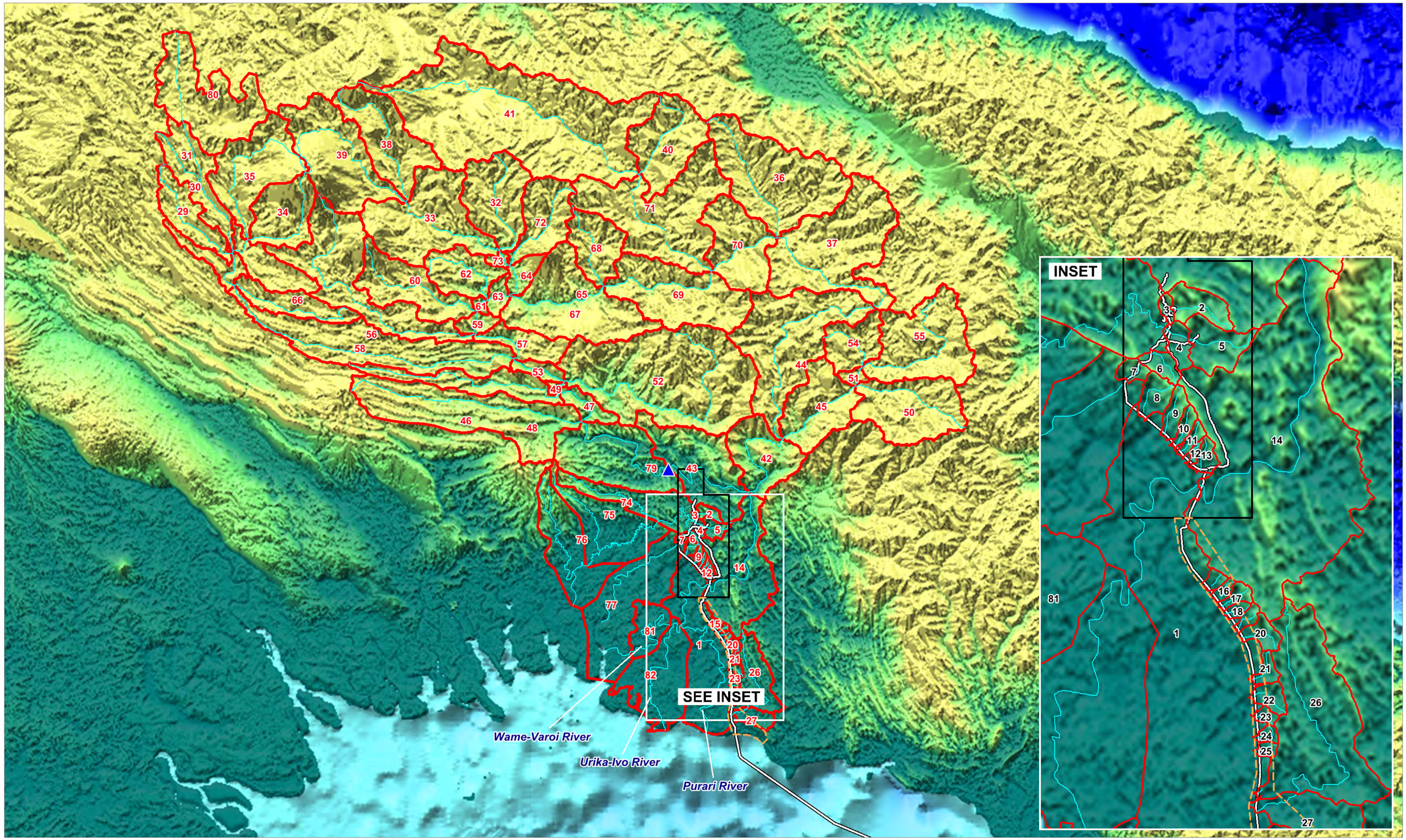
Intensity Frequency Duration (IFD) tables for each of the 80 sub-catchments are estimated using the Papua New Guinea Flood Estimation Manual (SMEC, 1990). Details on the methodology and results are presented in the Waterways Modeling Report (see Appendix A). IFDs tables provide the rainfall intensity (mm/hr) for storm durations for different ARI events (i.e. 2, 5, 10, 20, 25, 50, 100 year events).

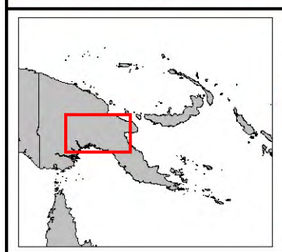
A site-based flood frequency analysis and regional flood frequency assessment were undertaken in order to provide a set of design event peak flow estimates for comparison to the URBS hydrological model design flows. These are described below.

The site-based flood frequency analysis was undertaken for the Purari gauging station (712400) located on Wabo Creek (location identified in Figure 6-16). While this is just upstream of the PRL-15 study area, it is considered to be representative of the expected flows associated with different ARI events. The site-based flood frequency analysis was undertaken using the software package Flike, which provides a comprehensive Bayesian analysis for a probability model fitted to gauged historic flow data. The primary outputs are estimated flows for a number of ARIs, as provided in Table 6-9. To provide some indication of uncertainty associated with these estimated flows, Monte Carlo limits were derived in Flike by undertaking Monte Carlo simulations to sample from a probability distribution for the recorded peak annual floods events to produce thousands of possible outcomes (5,000 samples in this analysis). The results are analyzed to provide probabilities of different outcomes occurring. The Monte Carlo method rarely samples in the very low probability regions, with samples in such regions called ‘rare events’. Results of the analysis are presented in Table 6-9 and Figure 6-17.

The regional flood frequency analysis was undertaken according to guidance provided in the Papua New Guinea Flood Estimation Manual (SMEC, 1990). Details on the methodology and results are presented in the Waterways Modeling Report (see Appendix A).

Flow estimates from both the site-based flood frequency analysis and the regional flood frequency assessment were compared, with the results shown in Table 6-10. As shown in the table, the site-based flood frequency assessment produces higher flow estimates than the regional assessment. However, the Papua New Guinea Flood Estimation Manual (SMEC, 1990) provides standard error bands and the differences in flows between these methods are within the stated standard error.





LEGEND

- PRL-15 Boundary
- Sub-catchments
- Onshore Export Pipeline Corridor
- Gauging Station
- Waterways
- Trunkline Infrastructure Options

-1000 -750 -500 -250 0 250 500 750 >1000

Elevation (m)

Title:
Study Area Sub-catchments

Figure: 6-16

Rev: A

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Table 6-9 Flood Frequency Analysis Flow Estimates for ARI Events at the Purari Gauging Station (712400)

ARI (years)	Peak flow (m^3/s)		
	Estimated Flows	Monte Carlo* - lower limit	Monte Carlo* – upper limit
1.001	790	230	1,620
1.01	1,540	700	2,500
1.1	3,130	2,100	4,100
1.25	4,190	3,180	5,140
1.5	5,170	4,250	6,150
1.75	5,810	4,913	6,830
2	6,280	5,400	7,310
5	8,490	7,580	9,660
10	9,580	8,600	10,880
20	10,410	9,374	11,980
50	11,240	10,130	13,280
100	11,720	10,540	14,180
200	12,110	10,850	14,950
500	12,530	11,160	15,920
1,000	12,770	11,310	16,620

*The Monte Carlo simulation provides a quasi 'limit of confidence' associate with an estimate, i.e. lower and upper limits either side of the flow estimate derived from the flood frequency analysis

Table 6-10 Comparison of Regional Flood Frequency and Site-based Flood Frequency Analysis Peak Flow Estimates for Purari Gauging Station (712400)

ARI (years)	Regional flood frequency peak flow (m^3/s)	Site-based flood frequency analysis peak flow (m^3/s)	Difference (m^3/s)	Difference (% of regional)*
2	5,310	6,280	970	18%
5	5,810	8,490	2,680	46%
10	6,140	9,580	3,440	56%
20	6,450	10,410	3,960	61%
50	6,840	11,240	4,400	64%
100	7,510	11,720	4,210	56%

* These differences between the flow estimates using the different techniques (regional versus site-based) are within the accepted error bands published in the Papua New Guinea Flood Estimation Manual (SMEC, 1990) for the regional flood frequency assessment and are hence considered acceptable.

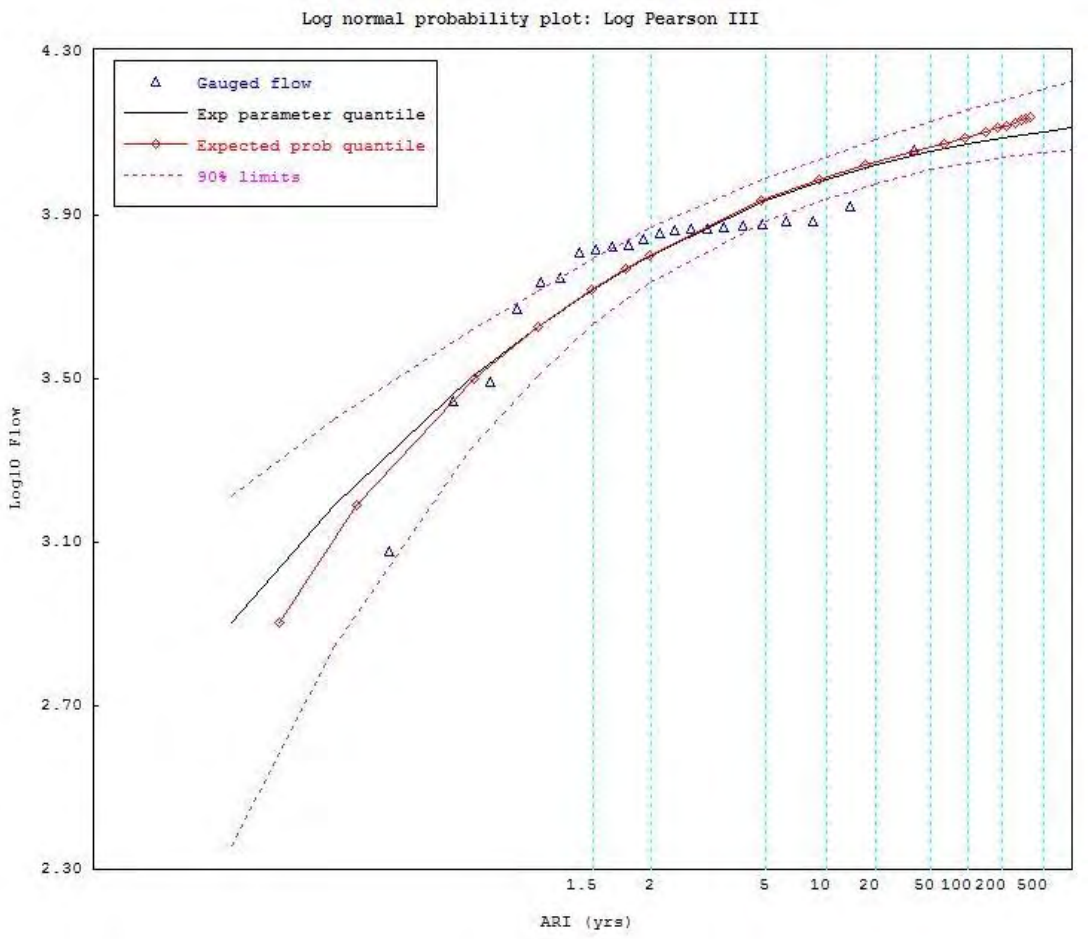


Figure 6-17 Site-based Flood Frequency Analysis Flow Estimates for ARI Events at the Purari Gauging Station (712400)

Figure 6-17 plots the results of the site-based flood frequency analysis. It is important to note that the gauged flows are plotted on this diagram using a simple plotting position formula (in this case the Cunnane plotting position). As noted in Geoscience Australia (2016), plotting positions should not be used as an estimate of the actual ARI of an event and the plotting location of the gauged flows does not need to align with the quantile plot results of the flood frequency analysis. It is not uncommon to observe a run of gauge data above or below the fitted frequency curve. This can be misinterpreted as evidence of poor fit when in fact it is more likely that the runs are an artefact of the way the data points are plotted.

Peak flows derived from the URBS hydrologic model are shown in Table 6-11 alongside comparative flows from the flood frequency analysis and regional flood frequency assessment at the Purari gauging station. The Papua New Guinea Flood Estimation Manual (SMEC, 1990) recommends the use of a 2.5 mm/hr 'continuing losses' rate when 'validating' a hydrologic model against flood frequency assessments. However, while this was considered suitable for the 100 year ARI event, based on a comparison between the URBS results and the flood frequency assessments for all ARI events, a reduced rate of 0.5 mm/hr was adopted.

Table 6-11 Comparison of the Estimated Peak Flows from URBS Hydrological Model to Flood Frequency Assessments at Purari Gauging Station (412400)

ARI (years)	Regional flood frequency peak flow (m^3/s)	Site-based Flood frequency peak flow (m^3/s)	URBS peak flow (m^3/s)
10	6,140	9,580	6,620
50	6,840	11,240	8,920
100	7,510	11,720	9,980

The hydrographs that were created from the URBS model were applied to the TUFLOW model as the inflows – see Section 6.5.

An assessment of the URBS model results provided an indication as to the 'critical storm duration' (i.e. time required for rainfall runoff from a storm to travel from the top of the drainage catchment to a specific location along the waterway) which cause peak flows in the target sub-catchments. For all target sub-catchments except 1, 26 and 27 the critical storm duration was six hours. The critical storm duration for sub-catchments 26 and 27 was 36 hours and for sub-catchment 1 was 72 hours. Longer critical duration are as a result of the large total catchment size.

6.5 Hydraulic Assessment

6.5.1 River Levels

River level gauging of the Purari River at Herd Base and Hou Creek indicate significant fluctuations in water level, comparative to a nominal 0 m level (indicative of a period when the river height is ~3 m). Comparable data from these locations is available on a daily time scale for the period 2013 to 2014, with additional data available at Herd Base for 2015 and part of 2016. This data is for a short period only and does not represent long-term patterns within the catchment but provides some demonstration of river behavior at these locations

This data indicates the following:

- Fluctuations in level of the Purari River recorded at both Herd Base and Hou Creek range between 10 m above and 6 m below the nominal 0 m (i.e. range of 16 m). These fluctuations occur throughout the year, and do not seem to following a particular seasonal pattern.
- In 2013 and 2014, the river level at Herd Base was below 0 m approximately 20% of the year (79 days in 2013, 78 in 2014) but up to 65% of the year in 2015 (238 days). In 2013, the river level was above 4 m around 20% of the time (72 days) but less than 10% in 2014 (30 days) and 1% in 2015 (2 days).
- The level of the Purari River recorded at Hou Creek was below 0 m almost 40% of the year (140 days in 2013, 114 days in January to September 2014). There were no days with records above 4 m.
- River level changes measured at Hou Creek appear to be reflected at Herd Base without significant delay, although occasional spikes at Hou Creek are not always reflected at water level at Herd Base.

6.5.2 Modeling Assessments

6.5.2.1 Overview

Sixteen separate TUFLOW hydraulic models were developed to represent the potential flow crossings along the trunkline and onshore export pipeline corridors (Figure 6-18). Flows for each of these 16 models were obtained from the 20 most relevant sub-catchments from the URBS hydrologic model. Some of these individual sub-catchments were combined in order to provide the most relevant flow at a particular potential crossing location for each TUFLOW model. This was undertaken due to the potential for flow paths from a number of waterway crossings to interact in larger flows. This approach better reflects the potential interactions of these flow paths and avoids model boundary effects. The combined sub-catchments are referred to as 'Target' sub-catchments.

The individual sub-catchments, discussed initially in Section 6.4.3.2 and mapped in Figure 6-16, were combined and assigned to the target sub-catchments as shown in Table 6-12 and Figure 6-18. The numbering of the target sub-catchments is the same as the TUFLOW model number to which the target sub-catchment is applied.

Table 6-12 Combination of URBS Sub-Catchments into Target Sub-Catchments

Catchment	Target Sub-Catchment Number	Individual URBS Sub-Catchment Included
Era River	S1	2, 3
Era River	S2	4, 5
Purari River	S4	8
Purari River	S5	9
Purari River	S6	10
Purari River	S7	11
Purari River	S8	12, 13
Purari River	S10	1
Purari River	S11	24, 25
Purari River	S12	15
Purari River	S13	17, 18
Purari River	S14	19, 20
Purari River	S16	21
Purari River	S17	22
Purari River	S18	23
Purari River	S20	26,27

The flood velocity, depths and levels for the 10, 50 and 100 year ARI events for each target sub-catchment are shown in the Waterways Modeling Report (Appendix A). Flood velocity is a measure of the speed of flood waters while flood depth and level are a measure of the height of flood waters. Level refers to the absolute level at which floodwaters sit, comparative to a datum (i.e. sea level)

while the flood depth provides the height of flood waters comparative to the underlying topography. Generally, this modeling identified two types of channels/floodplains in the study area. These are:

(1) Well-defined channels/floodplains, i.e. sub-catchments with a single main channel within the flood extent. These occurred in smaller tributaries in the upper Era River catchment (S1 and S2) and similarly small tributaries of the Purari River in PRL-15 (S4, S5, S6, S7 and S8). The Purari River from Herd Base to the Purari River oxbow lake (S10) and a small tributary in the Purari River delta (S18) also had these characteristics.

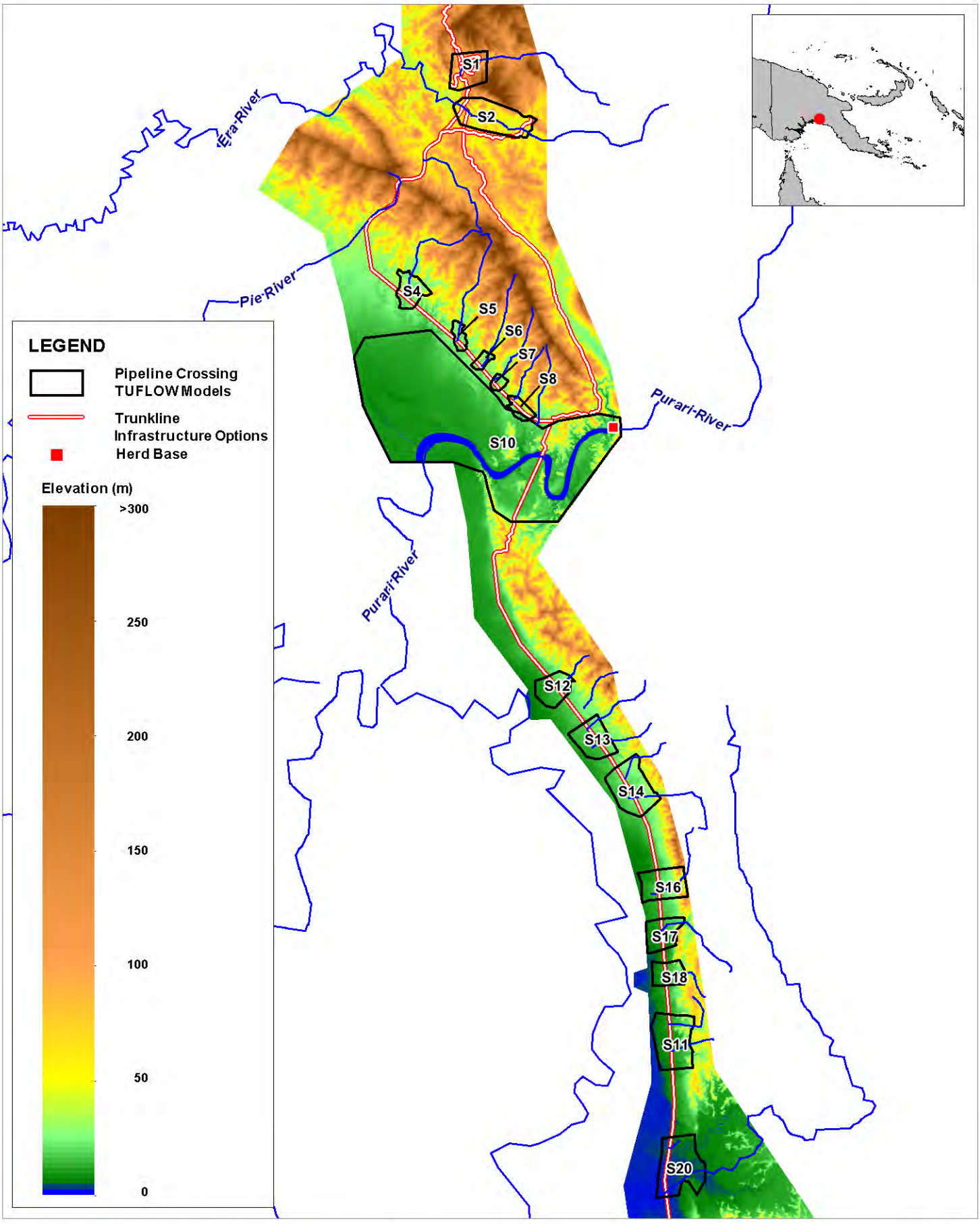
(2) Poorly defined channels/floodplains, i.e. sub-catchments with multiple intermingling channels across a wide floodplain. These occurred in all sub-catchments south of Herd Base except for S10 and S18 (i.e. S11, S12, S13, S14, S16, S17 and S20). The multi-channel floodplains are more common in the tributaries flowing to the Purari River delta.

For sub-catchments with well-defined channels, flood extents and depths tend to be similar for each ARI event as floodwaters are constrained by the limits of the channel. While flood extents tend to be lowest for these channels, flood depths and velocities tend to be higher. By contrast, flood extents are larger for poorly defined channels/floodplains but flood depths velocities tend to be lower.

Table 6-13 presents the peak modeled velocity within each of the modeled sub-catchments for the 10, 50 and 100 year ARI events. The highest modeled flood velocity for the study area was at S8 (tributary of Purari River in PRL-15) where a velocity of 7.8 m/s was modeled to occur during the 100 year ARI event.

Table 6-13 Peak Modeled Velocities for Each of the Model Sub-catchments

Target sub-catchment	Channel/floodplain type	Maximum velocity (m/s)		
		10 year ARI	50 year ARI	100 year ARI
S1	Well-defined/constrained	5.1	5.4	5.6
S2	Well-defined/constrained	4.1	4.1	4.1
S4	Well-defined/constrained	3.1	3.1	3.1
S5	Well-defined/constrained	2.2	2.5	2.5
S6	Well-defined/constrained	3.3	3.3	3.3
S7	Well-defined/constrained	2.9	3.2	3.3
S8	Well-defined/constrained	7.6	7.7	7.8
S10	Well-defined/constrained	4.5	4.6	5.0
S11	Poorly-defined/multi-channel	2.7	2.7	2.7
S12	Poorly-defined/multi-channel	3.0	3.0	3.1
S13	Poorly-defined/multi-channel	2.3	2.8	3.0
S14	Poorly-defined/multi-channel	1.8	1.9	2.0
S16	Poorly-defined/multi-channel	3.4	3.5	3.5
S17	Poorly-defined/multi-channel	2.0	2.0	2.1
S18	Well-defined/constrained	3.0	3.5	3.7
S20	Poorly-defined/multi-channel	2.2	2.5	2.6



Title:

TUFLOW Model Extents within the Study Area

Figure: 6-18

Rev: A

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Approx. Scale

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Based on results presented in Appendix A, the majority of sub-catchments experienced only minor changes in floodwater velocity between different ARI events. The greatest increase in peak velocity for the modeled catchments between the 10 year and 100 year ARI events was 0.7 m/s for catchment S18. The sub-catchments with the most substantial changes (when comparing the 10 and 100 year ARI events) are S5 and S7 (both 12% increase), S20 (15% increase), S18 (19% increase) and S13 (23% increase). All other sub-catchments have a variation of 10% or less when comparing the 10 and 100 year ARI events. There are no sub-catchments with a change greater than 10% in velocity between the 50 and 100 year ARI events, with six sub-catchments showing no change at all.

6.5.2.2 PRL-15 Oxbow Wetlands and Herd Base

Sub-catchment S10 includes the area between Herd Base and immediately downstream of the PRL-15 oxbow wetlands. This is the area in which the onshore export pipeline corridor crosses the Purari River.

The catchment here is well-defined and constrained. As a result, flooding is mostly contained within the river, with some backflow occurring within adjoining tributaries. Velocity is moderate, with some areas of higher velocity associated with the 50 and 100 year ARI events.

Despite the above, the PRL-15 oxbow wetlands (contained within S10) experience flood behavior more consistent with a poorly defined/multi-channel area. Flooding here is widespread but shallow and low velocity. Inundation of the wetlands from the river occurs in each of the 10, 50 and 100 year ARI events, with little difference between these. Flood depths are expected to be below 3.0 m during each of the events, with the deepest flooding occurring in the area occurring between the tie channels, oxbow lake and Purari River.

Details of inundation on a more frequent basis (i.e. less than the 10 year ARI event) are not available from the modeling undertaken. However, the oxbow lake within the wetlands is expected to be inundated by water from the main channel of the Purari River (i.e. there will be connectivity between the lake and river) on an annual basis, taking into account topography, river flow and observations made within the field. Highly localized rainfall in the area north of the wetlands may also cause backflow events to occur, i.e. where water within the oxbow lake overflows into tie channels and ‘pushes’ back water flow into these channels from the Purari River.

Flooding at Herd Base is associated with backflow into Kuku Creek from the Purari River. This reaches depths up to 3.0 m in areas immediately adjoining the creek. The modeled velocity of waters associated with this flooding is slow (less than 0.5 m/s). Similar conditions have also been simulated at Oyomo Creek, although flooding here is expected to be more dispersed (i.e. extends beyond the area immediately adjoining the creek).

NOTE: The above information is based on uncalibrated and unvalidated modeling undertaken at this location which should be treated with caution due to limitations in bathymetry and streamflow data. However, it is considered a fair representation of inundation events within this area.

6.6 Sediment Transport and Loads

6.6.1 Previous Studies (Pickup, 1983)

Sediment transport rates in the Purari and Aure rivers are closely aligned to rainfall runoff. This is shown in the sediment rating curve developed by Pickup (1983) utilizing data from SMEC-NK (1977), shown in Figure 6-19. Based on this rating curve, up to 57 million tons of sediment are expected to be transported in the Purari River at Wabo each year with a further ~48 million tons from the Aure River (Pickup, 1983). NOTE: The estimate from SMEC-NK for the Purari River at Wabo differs from modeled values by Pickup (1983; see below) which indicate a volume closer to 40 million tons. The contribution of anthropogenic activities (e.g. land use conversion) to the total sediment load in the Purari River catchment is expected to be minor (Pickup, 1983).

Modeling undertaken by Pickup (1983) as part of the EIS for the Wabo Hydroelectric Project described the composition of sediment contribution from the Purari (upstream of Wabo) and Aure rivers, together with the total output through the Purari delta. This is shown in Table 6-14. This indicates that 55% of the volume of sediment delivered to the Purari River in the area of PRL-15 comes from the Aure River. In particular, the majority of the clay within the Purari River is derived from the Aure River. Downstream of the Aure River confluence, the Purari River appears to fairly stable, with the sediment outflow correlating strongly to this modeled inflow (Pickup, 1983). A slight increase in sand outflow (6% at Aure River to 9% at delta) is expected to represent slight levels of erosion.

Despite this stability, however, Pickup's modeling suggests redistribution of sediment does occur downstream of Wabo as a result of local erosion and deposition (Pickup, 1983). In particular, Pickup noted higher erosion occurring between the Aure River junction and Bevan Rapids (upstream of Herd Base), with redistribution of most of this material between Herd Base and the PRL-15 oxbow wetlands.

Soils throughout the study area are predominantly strongly weathered clay soils (dystropepts) derived from mudstone, with alluvial sandy clays accumulated on river terraces – see Upstream Geology, Terrain and Soils Baseline Report (SLR, 2017; Part 1 in ESBS Dossier). Mudstone in particular is susceptible to erosion. Given the high levels of rainfall that occur in the area, sedimentation with the Purari River is an ongoing process.

Table 6-14 Modeled Sediment Input and Output for Purari River

River	Sediment input/output (m^3/year)		
	Clay	Silt	Sand
Sediment load to lower Purari River			
Purari River, upstream of Wabo	13.90×10^6	22.40×10^6	3.84×10^6
Aure River	27.07×10^6	20.20×10^6	1.22×10^6
Sediment load to Purari Delta			
Purari delta	40.97×10^6	42.60×10^6	5.54×10^6

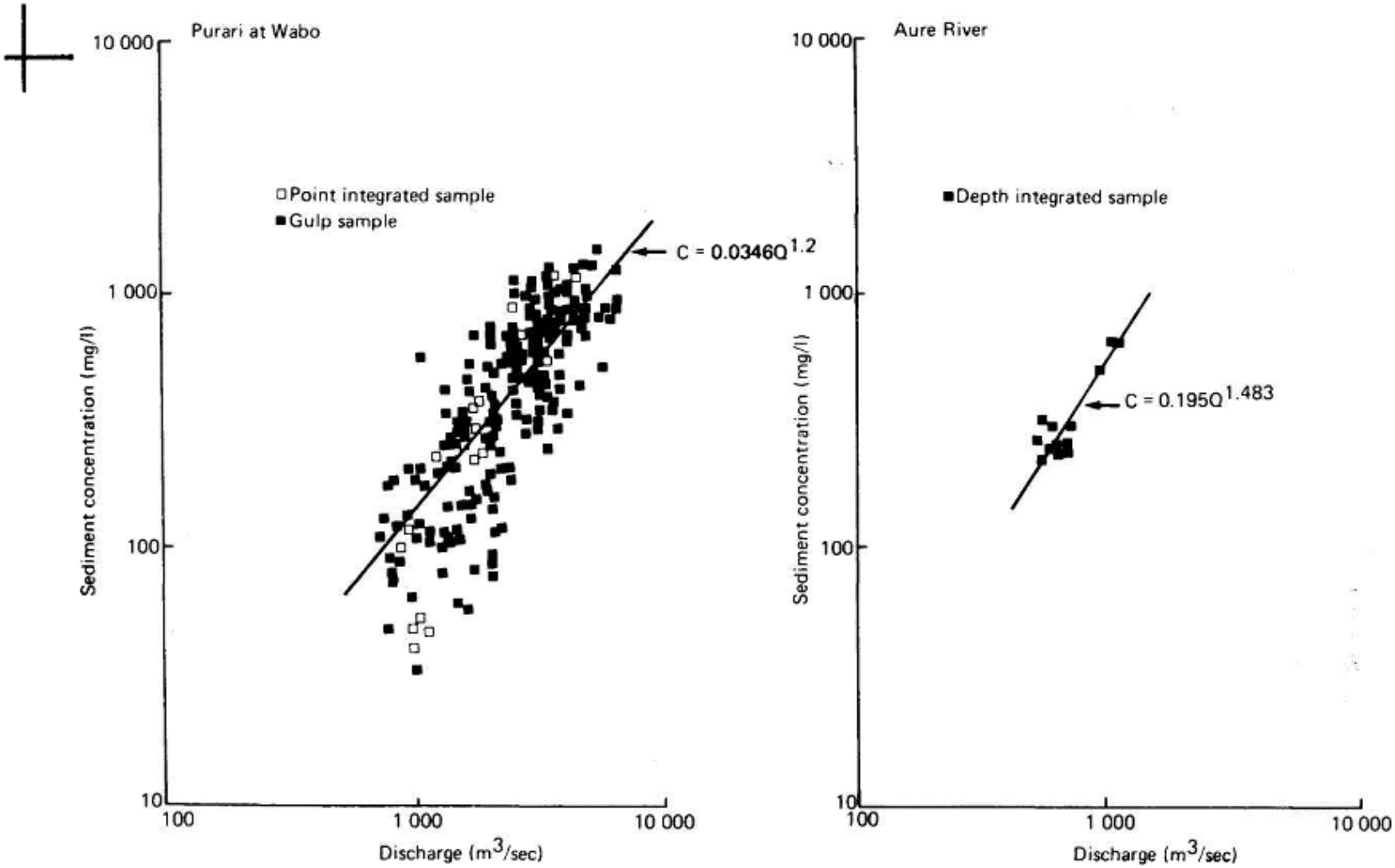


Figure 6-19 Sediment Rating Curves for the Purari and Aure Rivers (reproduced from Pickup, 1983)

6.6.2 Present Study

The catchment modeling undertaken by BMT WBM provides a statistical summary of runoff volume and total suspended solids (TSS) loads within the study area. This includes consideration of streamflow modeling, discussed in Section 6.4.2.2. These results are based on the same reporting locations and sub-catchments shown in Figure 6-11.

The modeled TSS load for the reporting locations is shown in Figure 6-20, which shows seasonality of TSS loads. Peak TSS loads are transported between May and August in response to the increased rainfall (and runoff volume) during the south-easterly trade wind season responsible for transporting sediment through the catchment. The mean annual TSS at the reporting locations is considered to be typical of the amount of sediment expected to be transported from the upper catchment, and is consistent with reported TSS loads documented in previous studies.

The modeled mean daily and mean annual TSS loads from each reporting location are shown in Table 6-15.

Table 6-15 Existing TSS Loads at the Selected Reporting Locations (Sub-catchments)

Reporting Location	Mean Daily TSS Loads (t/day)	Mean Annual TSS Loads (t/year)
1 (Purari River upstream of PRL-15)	64,702	23,390,045
2 (Hou Creek)	67	24,332
3 (Boa Creek)	14	4,931
4 (Mena River)	112	40,506
5 (Kuku Creek)	27	9,771
6 (Purari River downstream of PRL-15)	80,948	29,263,023

At Location 1, the mean annual TSS loads were approximately 23 million t/year, and at Location 6 were approximately 29 million t/year. These reported values are within the estimations made by Pickup and Chewings (1987) (noting that the Source Catchments model only estimates suspended loads and not bed loads), with Location 6 receiving sediment from both the Purari and Aure River catchments. The reporting locations within PRL-15 (i.e.; locations 2 to 5) had considerably lower mean annual TSS loads, between 0.1% (Location 2) and 0.2% (Location 4) of the TSS load at Location 1. Furthermore, even lower TSS loads were modeled at Location 3 and Location 5, which represented approximately less than 1% of the mean annual TSS loads at Location 1. This is reflective of the smaller contributing catchment areas within the PRL-15 site.

These results indicate that the dominant contribution of TSS loads in the Purari River downstream of Hathor Gorge come from the Aure River catchment rather than PRL-15 catchments. Total volumes discharged from the PRL-15 sub-catchment are negligible, representing less than 1% of the 6 million t/year difference in TSS loads between Locations 1 (upstream of PRL-15) and 6 (downstream of PRL-15).

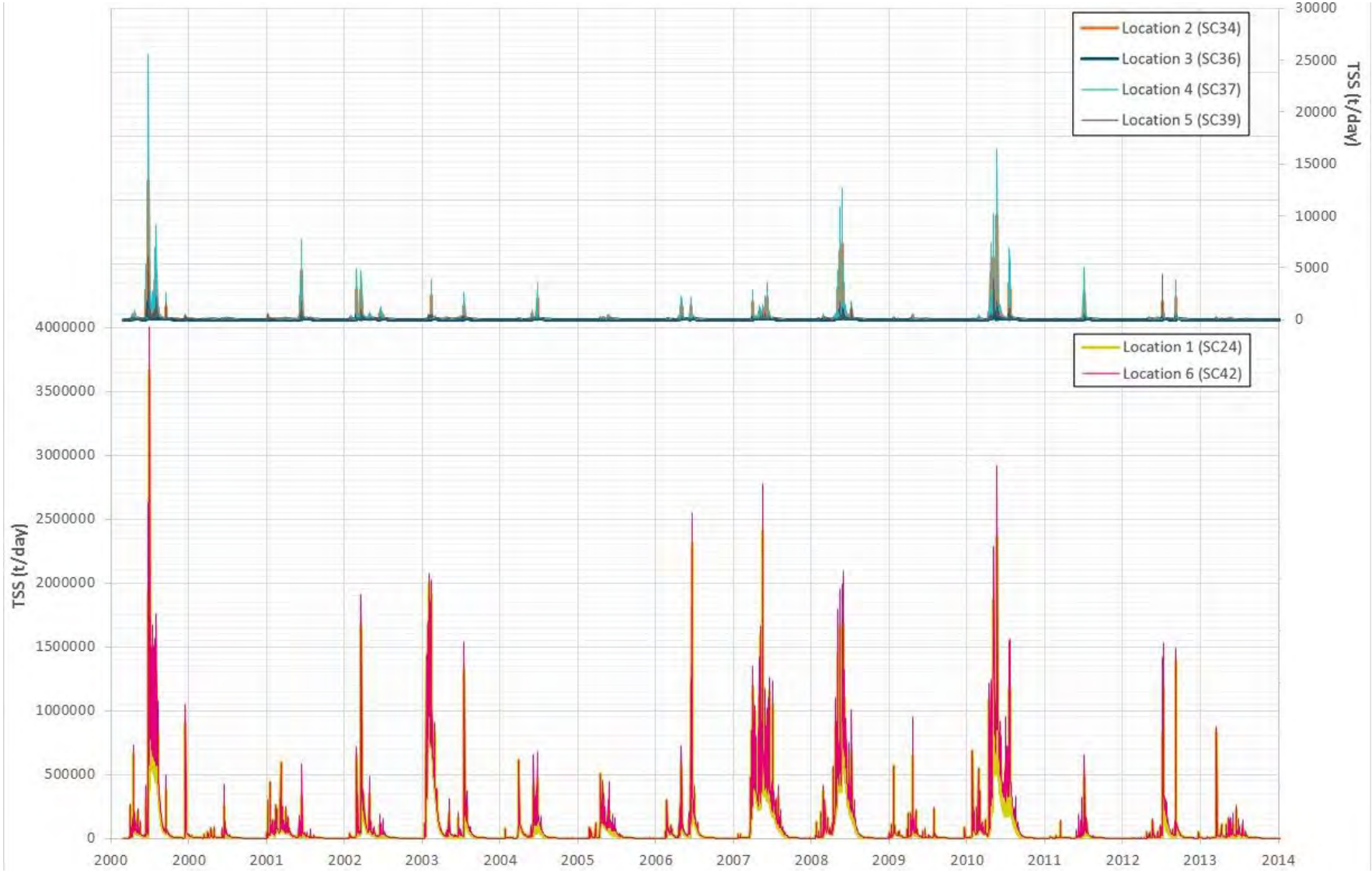


Figure 6-20 TSS Load at Selected Reporting Locations

7 Conclusions

The EIS/ESHIA for the Papua LNG Project requires consideration of the relevant baseline conditions for hydrology and meteorology. While some previous studies have been conducted in the Purari River catchment, further studies have been required in order to provide an appropriate baseline characterization. This has been the case in particular for hydraulics within the study area, with no known historical studies having conducted flooding assessments.

Hydrological, hydraulic and sedimentological modeling was conducted using available data from the study area as well as design data in order to satisfy the requirements of the EIS/ESHIA. The key findings of this modeling together with existing literature are as follows:

- The Purari River is a large meandering river for most of its length within the study area. As a result, it is characterized by scour and deep channels on the outside of bends and a shallow, depositional environment on the inside of bends. The morphology of the river is also highly variable.
- As a result of scour, a semi-continuous channel of up to 7 m depth is expected to be available from the mouth of the river (inside the bar) to Herd Base in normal conditions.
- Cross-sections of the river bed vary based on location and the influence of tributary streams. A cross-section upstream of Herd Base (and Kuku Creek) has a U-shaped bed while a nearby section, downstream of Herd Base and Kuku Creek, features a significant in-stream bank caused by sediment deposition from Kuku Creek, with deep scour on the opposite side of the creek.
- The Purari River mouth features a significant shallow bar, caused by coastal processes in this area.
- The two seasons of the study area are the northwest monsoon and the southeast trade winds seasons. Wind roses for PRL-15 produced from meteorological modeling suggest little change between seasons in the dominant wind directions. This may be a result of a low-level convergence (i.e. zone where two prevailing flows meet and interact) over PRL-15.
- Winds along the coastline are much higher and more closely linked to changes in season than further inland.
- A temperature-elevation relationship is noted in the Purari River catchment, with areas at lower elevation having higher temperature ranges than higher in the catchment. However, along the coast, sea breezes cause a reduction in the maximum temperature in this area.
- Temperature does not vary significantly between months, with more change expected to occur across years.
- The south-easterly trade wind season in Papua New Guinea occurs from May to October. During this season very heavy rainfall occurs in the Purari River catchment downstream of Hathor Gorge, as a result of the low level convergence. This contrasts with rainfall in upper parts of the catchment (including the Aure River catchment) where rainfall is highest during the northwest monsoon (December to March).

- Significantly higher annual rainfall occurs downstream of Hathor Gorge than in the upper part of the Purari River catchment.
- The main catchment of the study area is the Purari River catchment. The main tributary of relevance to the Purari in the area of PRL-15 is the Aure River. Other catchments within PRL-15 are the upper tributaries of the Pie and Era rivers. A total of 80 sub-catchments have been identified for all of the Purari, Pie and Era rivers, including sub-catchments located upstream of PRL-15.
- Contribution of streamflow from sub-catchments in PRL-15 to the Purari River are negligible in comparison to contributions of the Aure River, based on comparisons between modeled upstream and downstream streamflows.
- The Purari River is capable of rapid changes in water level associated with changing flow events. This is indicated by river level gauging undertaken at Herd Base.
- Flood events and low flow events within the study area can occur throughout the year but the largest tend to occur in association with seasonal rainfall patterns. Due to the difference in rainfall patterns at PRL-15 comparative to the upper Purari River catchment, both flooding and low flow events can occur in the southeast trade winds season (in particular during June to September). This is the result of high rainfall occurring at this time in PRL-15 (causing flood events) but low rainfall in the upper catchment (causing low volumes flowing into the river in the vicinity of PRL-15).
- Pickup and Chewings (1983) indicate mean daily discharge from the Purari River to be 2,360 m^3/s, with a maximum up to 10,405 m^3/s and an average minimum of 1,920 m^3/s. The Aure River mean daily discharge is 307 m^3/s.
- The Aure River, by contrast, tends to flood during the north-westerly season (February to March) when rainfall is high, and has low flows in the south-easterly season. No information is available regarding flooding and low flow events in the Pie and Era river catchments but this is expected to strongly correlate to the Purari River downstream of Hathor Gorge.
- Variability from year to year in the nature of flooding and low flow events across years is relatively low.
- The sub-catchments of interest in the study area can generally be grouped into two main types of channel/floodplain. These are well-defined channels, marked by flooding constrained to a single channel, and multi-channel floodplains where flood events spread over a large area. Well-defined channels are more common in the upper tributaries of the Era River and the tributaries of the Purari River in PRL-15, while multi-channel floodplains are more common in the tributaries flowing to the Purari River delta.
- Of these two channel types, flood velocities and depths, are highest and flood extents lowest in the well-defined channels, and the reverse for multi-channel floodplains. The flood extent and height across different ARI events for well-defined channels does not change significantly due to the containment of flood water within the stream channels.

- Flood velocity and depth does not change significantly between the 10, 50 and 100 year ARI events, particularly when comparing the 50 and 100 year events.
- Simulations of flooding at the PRL-15 oxbow wetlands, Oyomo Creek and Herd Base peak flooding heights of less than 3.0 m and all three locations with low velocities. Flooding at Herd Base is associated with back flow from Kuku Creek and is confined to areas immediately adjoining the creek. Oyomo Creek has a similar flooding pattern but with a larger extent. Flooding at the PRL-15 oxbow wetlands is very widespread and deepest in the area formed between the tie channels, oxbow lake and Purari River.
- The PRL-15 oxbow wetlands are expected to be inundated by water from the Purari River on an annual basis.
- Sediment transport within the Purari River is predominantly composed of silts and clays, with a significant contribution of clays from the Aure River. In total, the Aure River is expected to contribute 55% of the sediment loads in the Purari River at the confluence of the two rivers, with only smaller amounts of sediment likely to be derived further downstream. This finding has been supported by catchment modeling, which indicates the sub-catchments in PRL-15 contribute less than 1% of the difference in sediment loads between the Purari River upstream and downstream of PRL-15.
- There is a strong relationship between rainfall and runoff throughout the study area, with sediment transport in the area of PRL-15 therefore highest during the wetter season (June to September for the Purari, Pie and Era river catchments; and February to March for the Aure River catchment).

8 Study Team

The study team responsible for the preparation of the Upstream Hydrology and Meteorology Baseline Report are listed in Table 8-1 below.

Table 8-1 Hydrology and Meteorology Study Team

Personnel	Role	Qualifications
Eoghain O'Hanlon	Technical Lead for Hydrology and Meteorology Hydrology and Hydraulics Modeling	Bachelor of Applied Science Master of Philosophy
Cathie Barton	Modeling Peer Review (Hydrology and Hydraulics)	Bachelor of Engineering Master of Engineering Science Register Professional Engineer of Queensland
Jessie Hayne	Catchment Modeling	Bachelor of Environmental Science
Luke Kidd	Catchment Modeling	Bachelor of Engineering Master of Environmental Science
Jeremy Visser	Study Coordinator	Bachelor of Laws, Bachelor of Environmental Management
Lyn Leger	Study Manager	Bachelor of Laws, Bachelor of Science (Honors) Master of Laws

9 Glossary and Abbreviations

2D	Two dimensional
ARI	Average Recurrence Interval
BFI	Baseflow Index
CEPA	Conservation and Environment Protection Authority of Papua New Guinea
CPF	Central processing facility
DEM	Digital Elevation Model
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CPF	Central Processing Facility
DEM	Digital elevation model
DES	Douglas Environmental Services
EHS Guideline	Environment, Health and Safety Guidelines, developed by the IFC as representation of good international industry practice
EIS	Environmental Impact Statement
Elk/Antelope Gasfield Project	Gas extraction, transport and processing project proposed by InterOil. Involves operation of Elk-Antelope gasfields in Gulf Province and transport to a LNG Plant on Purari River, Gulf Province.
ESBS	Environmental and Social Baseline Study
ESHIA	Environment, Social and Health Impact Assessment
FEM	Papua New Guinea Flood Estimation Manual (SMEC, 1990)
GIIP	Good international industry practice
GL-ENV/02/2004	*Guideline for Conduct of Environmental Impact Assessment & Preparation of Environmental Impact Statement*, prepared by (former) Department of Environment and Conservation (2004)
GS EP ENV 120	*Environmental impact assessment of E&P activities*, General Specification prepared by Total E&P (2007)
GS EP ENV 111	*Environmental Baseline and Monitoring Studies: Onshore Sites*, General Specification prepared by Total E&P (2012)
GS EP ENV 112	*Environmental Baseline and Monitoring Studies: Offshore and Nearshore Sites*, General Specification prepared by Total E&P (2012)
IFC	International Finance Corporation
IFD	Intensity frequency duration
IUCN	International Union for the Conservation of Nature
IPIECA	International Petroleum Industry Environmental Conservation Association
ITCZ	Inter-tropical Convergence Zone
JCU	James Cook University
LiDAR	Light Detection and Ranging elevation data
LNG	Liquid natural gas
NK	Nippon Koei
OECD	Organization for Economic Cooperation and Development

Papua LNG	Gas extraction, transport and processing project proposed by TEP PNG. Involves operation of Elk-Antelope gasfields in Gulf Province, and onshore and subsea pipeline via Orokolo Bay to LNG Plant at Caution Bay, Central Province
PDL	Petroleum Development License
PL	Pipeline License
PPFL	Petroleum Processing Facility License
PRL	Petroleum Retention License
Project	The Papua LNG Project
QA/QC	Quality assurance/quality control
SMEC	Snowy Mountains Engineering Corporation Limited
SRTM	Shuttle Radar Topography Mission
Study Area	The catchments of the Purari, Era and Pie rivers
TEP PNG	TOTAL E&P Papua New Guinea
TSS	Total Suspended Solids
URBS	Unified River Basin Simulator

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Appendix A Papua LNG Project Waterways Modeling Report

Papua LNG Project: Waterways Modeling Report

Prepared for Total E&P PNG Limited

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BMT WBM Pty Ltd
Level 8, 200 Creek Street
Brisbane Qld 4000
Australia
PO Box 203, Spring Hill 4004

Tel: +61 7 3831 6744
Fax: + 61 7 3832 3627

ABN 54 010 830 421

www.bmtwbm.com.au

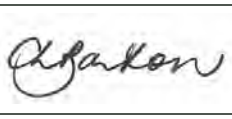
Document:	R.B21414.002.00D.docx
Title:	Papua LNG Project: Waterways Modeling Report
Project Manager:	Lyn Leger
Author:	Eoghain O'Hanlon, Luke Kidd, Jessie Hayne
Client:	ERIAS Group
Client Contact:	Clark Monahan
Client Reference:	01215B

Synopsis: **Technical report for the hydrological, hydraulic and rainfall-runoff (catchment) modeling undertaken for the Papua LNG Project EIS/ESHIA**

TECHNICAL REPORTS SERIES

Report Number	Description
0	***Papua LNG Modeling Report – Waterways Modeling***

REVISION/CHECKING HISTORY

No.	Purpose	Date	Checked by		Issued by	
D	Final Report	21-Aug-17	CLB		JDV	
			LJK			

Executive Summary

Background and Approach

This Modeling Report documents the technical methodology and results for modeling activities associated with the Hydrology and Meteorology Study component of the Papua LNG Project EIS/ESHIA. This report has been prepared for ERIAS Group and supports other technical reports prepared by BMT WBM as part of the EIS/ESHIA.

The modeling activities undertaken consisted of the following:

- Hydrological modeling, using Unified River Basin Simulation (URBS) software, to identify baseline flow events for the study area
- Hydraulic modeling, using TUFLOW, to identify baseline flood levels and velocities at waterways within the pipeline corridor for the Project and to identify Project infrastructure areas of high flooding risk
- Catchment modeling, using Source Catchments, to identify baseline rainfall-runoff conditions and sediment loads within the Purari River and changes that would be expected following development of the Project.

Modeling Methodology

Hydrological Modeling

The hydrological modeling developed an uncalibrated and unvalidated hydrological model to contribute to hydraulic assessments. Development of the model required development of sub-catchments for the study area together with rainfall analysis. In addition, a flood frequency assessment was undertaken to provide a quasi-validation exercise for the URBS model.

The catchment delineation for the study area was undertaken using Shuttle Radar Telemetry Mission (STRM) data as this was the only topographic data that covered all the catchments that the pipeline crosses. The delineation was undertaken using the software package CatchmentSIM. Eighty sub-catchments were delineated across the Purari, Pie and Era River catchments.

This study has relied heavily on the development of design rainfall derived from the PNG Flood Estimation Manual. Design rainfall for all of the sub-catchments with in the Purari, Pie and Era River catchments was estimated. This included the creation of intensity frequency duration (IFD) tables for each sub-catchment.

A flood frequency analysis (FFA) was undertaken for the stream gauge upstream of Wabo Creek on the Purari River using 22 years of records. To provide some additional validation of the hydrology model and the FFA, an assessment using the PNG Flood Estimation Manual - Regional Flood Frequency (RFF) Method was undertaken for the catchment to Purari River upstream of Wabo Creek.

The sub-catchments of the Purari, Pie and Era River catchments, that were delineated using CatchmentSIM, were used to develop an Unified River Basin Simulator (URBS) hydrologic model. The URBS model was validated to the FFA and RFF stream gauge on the Purari River Upstream of Wabo Creek.

Hydraulic Modeling

Sixteen TUFLOW models have been developed for the hydraulic assessment of sub-catchments associated with likely infrastructure locations (Figure 4-6). The TUFLOW models have used LiDAR to inform their model topography. Fifteen of the models have been developed on a 5 m grid with the remaining model (S10) utilizing a 10m due to its much larger model extent. The LiDAR within the S10 Purari River model has the Purari River at a constant level of 4.8 m and has no bathymetry, as LiDAR cannot penetrate water. The land use/model hydraulic roughness has been digitized from aerial photography. The critical durations 10 year, 50 year and 100 year average recurrence interval (ARI) events were simulated in the hydraulic models; this was the 6 hr duration for all models, except the S10 (72 hr) and the S20 (36 hr). Calibration of these models has not been possible due to lack of calibration data.

Rainfall-Runoff and Sediment Transport Modeling

A hydrological model capable of simulating a continuous longer-term historical period was prepared for the study. The rainfall-runoff (catchment) model, was used to estimate the flow (runoff) volume and load of total suspended sediment (TSS) for the Purari River catchment. Partial calibration of rainfall-runoff model parameters was undertaken for Waghi River sub-catchment in lieu of adopting default model parameters which are shown to be unsuitable for the study catchment. Flow calibration was undertaken using the Calibration Wizard in Source Catchments for the period 1967 to 1980 using daily streamflow data on the Waghi River (station 704850). Only a modest calibration result could be obtained due to the quality and length of overlapping rainfall and streamflow data. TSS was not calibrated due to the lack of continuous TSS data available across the catchment.

TSS was modelled using the power function model available within the Source modeling platform. This model defines an empirical relationship between catchment derived total TSS concentrations and catchment flows. This method has successfully been used in other large-scale catchment modeling projects in Papua New Guinea. The power function inputs were verified against field data collected as part of the Project.

Baseline scenario modeling was undertaken for the period 2000 to 2015 using the Tropical Rainfall Measuring Mission (TRMM) data which provides a contemporary estimate of rainfall for the study region and the basis for impact scenario modeling.

Baseline Modeling Results

Hydrological Modeling

A comparison of the peak flows obtained from the FFA to the RFF indicates that the RFF tends to produce much lower peak flood flows (Table 4-9).

The URBS model was able to achieve a good match with the 100 year ARI event using the suggested continuing losses, but was unable to replicate similar flows for the 10 year and 50 year ARI events. Reducing the continuing losses to 0.5 mm/h and adjusting the URBS Alpha and Beta parameters achieved a better match for the 10 year, 50 year and 100 year ARI events was achieved when compared to the FFA and RFF estimates for those events (Table 4-11).

Hydraulic Modeling

The sub-catchments of interest in the study area can generally be grouped into two main types of channel/floodplain. These are well-defined channels, marked by flooding constrained to a single channel,

and multi-channel floodplains where flood events spread over a large area. Well-defined channels are more common in the upper tributaries of the Era River and the tributaries of the Purari River in PRL-15, while multi-channel floodplains are more common in the tributaries flowing to the Purari River delta.

Of these two channel types, flood velocities are highest and flood extents lowest in the well-defined channels, and the reverse for multi-channel floodplains. The flood extent across different ARI events for well-defined channels did not change significantly due to the containment of flood water.

Rainfall-Runoff and Sediment Transport Modeling

A comparison of streamflow and TSS loads in the Purari River between locations upstream and downstream of PRL-15 identified significant contribution is made by inflows from sub-catchments between these locations. However, when these differences were compared to the contribution of PRL-15 sub-catchments, it is evident that inputs from PRL-15 are negligible, with most inflows coming from the Aure River. This is consistent with findings of Pickup and Chewings (1983).

List of Symbols and Abbreviations

A	Catchment Area (km^2 or ha)
a,b,c	Blench and Lacey exponents
α	URBS storage lag parameter
Alpha	URBS storage lag parameter
AREA	Catchment Area (km^2 or ha)
AEP	Annual Exceedance Probability
ARI	Average Recurrence Interval
B	URBS Catchment Routing parameter
d	Depth of flow (m)
D_{50}	The medium diameter of bed material (mm)
DEM	Digital Elevation Model
FFA	Flood Frequency Analysis
IFD	Intensity Frequency Duration
K	Blench and Lacey Coefficient
KARST	Proportion of Karstic landform in catchment
LiDAR	Light Detection and Ranging elevation data
M	URBS Catchment routing exponent
P_2	Point Daily Rainfall with an annual series return period of 2 years
P_{100}	Point Daily Rainfall with an annual series return period of 100 years
PNG	Papua New Guinea
q	The flow discharge per unit width of the main channel ($m^3/s/m$)
Q_2	Peak Discharge with an annual series return period of 2 years (m^3/s)
Q_{100}	Peak Discharge with an annual series return period of 100 years (m^3/s)
Q_d	Design discharge (m^3/s)
RFF	PNG Flood Estimation Manual Regional Flood Frequency method
SHAPE	Shape index of catchment SHAPE = Z^2/Area or Area/Z^2 (adopt the value that is greater than 1.0) (see Figure 15 of the FEM)
SWAMP	Swamp or flood prone land index of the catchment
SLOPE	Slope index of main channel of catchment (m/km or %) (see Figure 15 of the FEM)
SRTM	Shuttle Radar Telemetry Mission elevation data

URBS	Unified River Basin Simulator (a hydrologic model)
W_f	Flow width at design discharge
y_{ms}	The mean scoured flow depth below the free surface (m)
y_0	Average flow depth in the section
Z	The distance from the outlet of the catchment through the centroid to a point that is perpendicular to the end of the mainstream of the catchment (see Figure 15 of the FEM)
z_t	Maximum scour depth at the cross section or reach in question (m)
$z_{t\ (mean)}$	Best fit curve for observed scour depth (m)
$z_{t(max)}$	Enveloping curve for maximum scour depth (fig. TS14B–1)

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1 Introduction

TOTAL E&P PNG Limited (TEP) PNG, a wholly owned subsidiary of TOTAL, is the leading joint venture partner for the Papua LNG Project (the Project). This Project involves the development of the Elk-Antelope gas field, which is located within Petroleum Retention License 15 (PRL-15) in Gulf Province, Papua New Guinea.

In accordance with Papua New Guinea legislation, International Finance Corporation (IFC) Performance Standards, and TOTAL'S corporate policies and standards, an Environmental Impact Statement/Environmental, Social and Health Impact Assessment (EIS/ESHIA) is being developed for the Project. This is being managed by ERIAS Group.

One of the components of the EIS/ESHIA is a hydrology and meteorology study. In order to complete the environmental and social baseline study (ESBS) and later impact assessment for this component, numerical modeling activities have been undertaken. These activities are intended to provide additional datasets to inform the baseline characterization of the study area and to identify the likely impacts of the Project. The modeling activities that have been undertaken for this component are:

- Hydrological modeling, using Unified River Basin Simulation (URBS) software, to identify baseline flow events for the study area.
- Hydraulic modeling, using TUFLOW, to identify baseline flood levels and velocities at waterways within the pipeline corridor for the Project and to identify Project infrastructure areas of high flooding risk.
- Catchment modeling, using Source Catchments, to identify baseline rainfall-runoff conditions and sediment loads within the Purari River and changes that would be expected following development of the Project.

This report presents a detailed description of the methodology utilized and results produced by these modeling activities. Specifically, this report includes the following:

(1) Description of modeling approach and modeling platforms/software used.

(2) Existing data used for modeling.

(3) Modeling methodology.

(4) Model results for baseline characterization.

(5) Recommendations for model improvement.

(6) Limitations of modeling.

2 Study Area Context and Modeling Approach

2.1 Introduction

This section provides a description of the study area and the modeling and technical assessments proposed for the EIS/ESHIA. This has been prepared in the context of the assessment requirements of the following standards:

- GL-Env/02/2004: Guideline for Conduct of Environmental Impact Assessment & Preparation of Environmental Impact Statement (CEPA, 2004)
- GS EP ENV 120: Environmental impact assessment of E&P activities (Total Exploration & Production, 2007)
- GS EP ENV 111: Environmental Baseline and Monitoring Studies (Total Exploration & Production 112)
- International Finance Corporation Performance Standards and Environmental, Health and Safety (EHS Guidelines).

It is important to note that for all the activities presented below, modeling has been recommended in accordance with standard practice for EIS/ESHIA. In addition, due to data paucity in relation to hydrology and meteorology, modeling is necessary to fill gaps in the context of the baseline environment and to predict expected impacts as a result of Project activities.

The study area for modeling activities is the entire Purari River catchment together with the Pie and Era river catchments – see Figure 2-1.

2.2 Catchment Setting and Hydrological Processes

2.2.1 Site Locality and Hydrological Setting

The Elk-Antelope gas field is located within Petroleum Retention License 15 (PRL-15) in Baimuru District, Gulf Province, approximately 120 km inland from the township of Kerema and 360 km northwest of Port Moresby. PRL-15 is located in the mid to lower reaches of the Purari River catchment and the north-eastern portion of the Era River catchment. The Era River catchment is much smaller, draining tributaries west of a ridgeline running through PRL-15. Both catchments flow into the Gulf of Papua.

The Purari River catchment is approximately 26,300 km^2 at Wabo, and approximately 33,670 km^2 at its outlet into the sea of the Gulf of Papua along the southern coast of PNG (Pickup & Chewings, 1983). The study catchment is bound by the Kikori and Vailala rivers. Within the study area, the Purari River flows in a south to south-easterly direction from Wabo to Deception Bay in the Gulf of Papua, bifurcating downstream of PRL-15 into three rivers, namely the Purari (east branch), Urika-Ivo (central branch) and Wame-Varoi (west branch) (Douglas Environmental Services [DES], 2010).

The topography of the study area is shown on Figure 2-2 This assessment is primarily focused on the main waterways within the Purari River catchment downstream of Hathor Gorge, located within or immediately adjacent to PRL-15. Major waterways within the study area include tributary rivers

above Hathor Gorge, e.g. Erave River, Kaugel River, Waghi River as well as interconnected wetlands and the main channel of the Purari River.

The predominant land uses within the Purari River catchment generally fall into one of two categories: undisturbed bushland and cleared rural areas which broadly correspond with extents of the inland southern fold mountains and highland valleys (southern, western and eastern highlands). The inland southern fold mountains surrounding the mid reaches of the catchment are steep, highly erodible, and have a higher proportion of naturally exacerbated sediment transport. In contrast, the highland valleys are more stable and have a greater coverage of vegetation, such as anthropogenic grasslands (Pickup and Chewings, 1983). These land use categories contribute to sediment transport and sediment generation processes, and generally dictate the contribution of sediment from a particular sub-catchment.

2.2.2 Geological Setting

The Purari River catchment has a geological setting reflective of its sediment producing capabilities and diverse topography. The inland southern fold mountains are comprised of exceedingly steep erodible escarpments with steep ridges that are conducive to landslides. When combined with high annual rainfalls (from 3500 to 8000 mm), this mountainous region produces the greatest amount of sediment load transported by the Purari River system (Pickup and Chewings, 1983).

The upper reaches of the Purari River catchment are comprised of more stable sediments covered by densely populated vegetation. The ash covered slopes of the highland valleys give rise to some sediment loads; however, as sediment transport rates are closely aligned to runoff in the catchment, the lower annual rainfall of the highland valley region (see below) results in lower sediment loads being transported by the system than the southern fold mountain region.

Soils throughout the project area are predominantly strongly weathered clay soils (dystropepts) derived from mudstone, with alluvial sandy clays accumulated on river terraces (Interoil, 2011). Mudstone in particular is extremely susceptible to erosion. Given the high level of rainfall that occurs in the study catchment, sedimentation within rivers is an ongoing process.

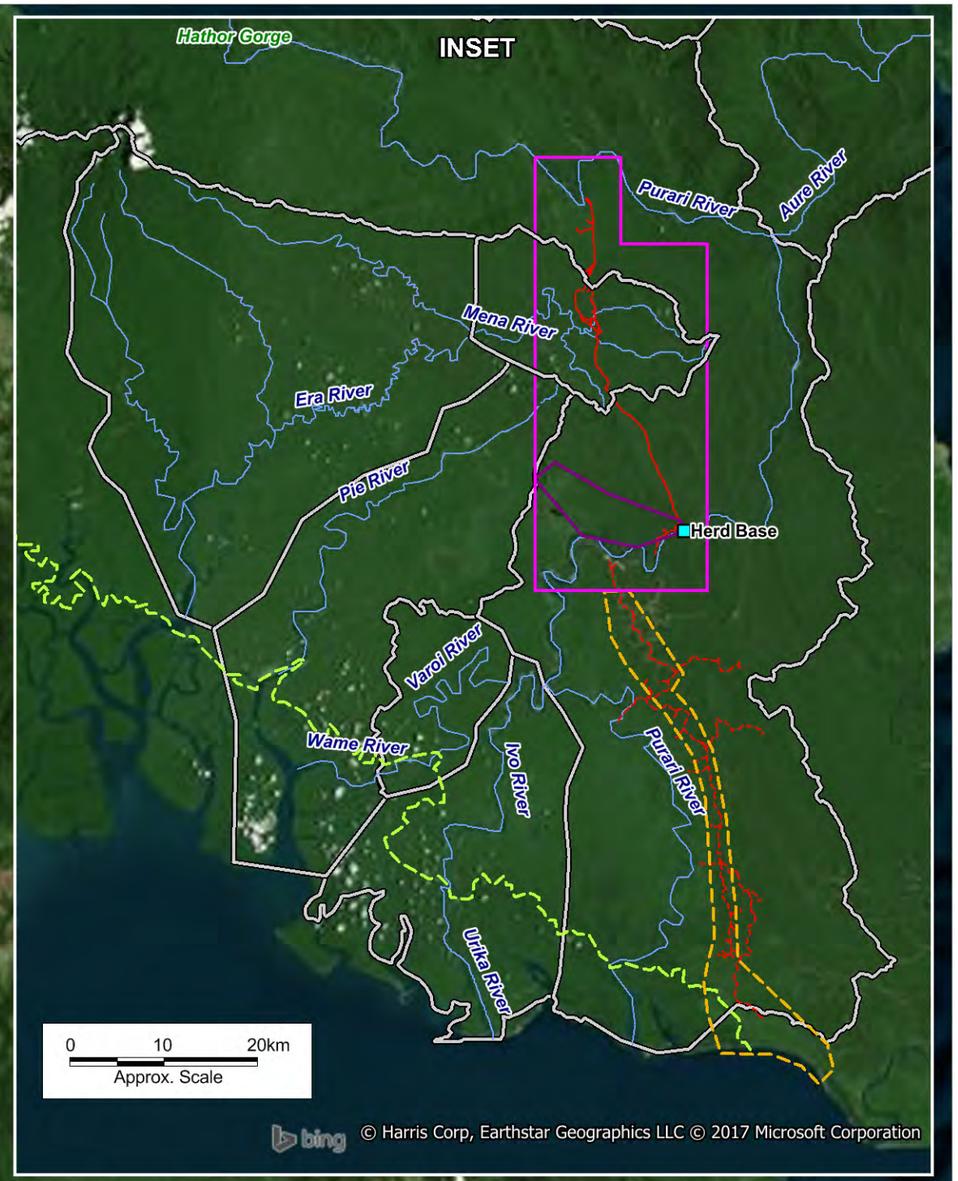
2.2.3 Climate and Seasonal Variation

The Purari River catchment is topographically diverse, measuring over 4,500 m above sea level at its highest point at Mt Wilhelm on the Bismarck Range along the upper reaches in the central highlands. The majority of the highland valleys in the mid-upper reaches of the catchment occur around 1,000 m above sea level (McAlpine *et al.* 1983). Hence, the drastic change in elevation between the upper and lower reaches of the catchment drives the variability of the climate of the Purari River catchment. At the edge of the inland southern fold mountains in the south-eastern portion of the catchment, the average annual rainfall is approximately 7,000 to 8,000 mm and decreases to approximately 2,000 to 3,000 mm in the north-western portion of the catchment.

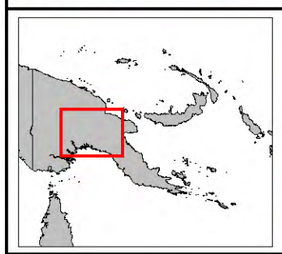
The PRL-15 area generally has a tropical climate that is relatively hot and humid throughout the year. The degree of humidity is related to the two main seasons: the south-eastern trade wind season and the monsoon season. Further inland, annual rainfall increases and there is less seasonality. Mean annual precipitation exceeds 3,500 mm and can reach 12,000 mm (Evesson, 1983). At Wabo, the mean annual precipitation exceeds 8,900 mm (Evesson, 1983). The Purari

catchment experiences reversed seasonality with mean maximum monthly rainfall occurring during the south-easterly trade wind season. As such, approximately 70% of the annual rainfall experienced by the inland southern fold mountains falls during the period extending from May to October each year. The highlands receive the majority of its rainfall during the north-westerly trade wind season between December and March. Between these distinct topographic regions are transitional zones that generally receive a stable amount of rainfall across all seasons (Pickup & Chewings, 1983).





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LEGEND

- Study Area
- Catchment Boundaries
- Waterways
- PRL-15 boundary
- CPF area
- Herd Base
- Narrowed Onshore Pipeline Corridor
- Indicative Estuarine Boundary
- Existing Roads
- Existing Tracks

Title:

Waterways Modelling Study Area

Figure: **2-1**

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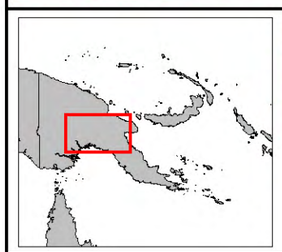
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Scale - Main Map

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MOUNT HAGEN
MENDI
KUNDIAWA
GOROKA
LAE
KEREMA



LEGEND

PRL-15 Boundary

Purari River Catchment

Waterways

Town

-1000 -750 -500 -250 0 250 500 750 >1000

Elevation (m)

Title:
Topography of Study Area

Figure: **2-2**

Rev: **A**

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Approx. Scale

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2.3 Modeling Approach

Modeling activities in the study area have been divided into the two following groupings:

- Hydrology and hydraulics – this includes all modeling and technical assessments associated with determining flow events and resulting flooding and scour
- Rainfall-runoff and sediment loads – this includes all modeling and technical assessments associated with rainfall-runoff processes and sediment transport.

Both sets of modeling activities include baseline and impact assessment components, however only baseline components are presented in this report.

2.3.1 Hydrology and Hydraulics

For the purposes of assessment of the hydrology and hydraulics in the study area, the following modeling activities have been undertaken:

- *Hydrology Assessment* – intended to quantify the flow rates and volumes during a design flood event. This utilized the PNG Flood Estimation Manual (SMEC, 1990) due to the data paucity associated with the sites.
- *Hydraulic Assessment* – intended to identify flood behavior in the study area and to quantify flood risk (but not to assess impacts of flooding on infrastructure or to inform infrastructure design).

2.3.2 Rainfall-Runoff and Sediment Loads

For the purposes of assessment of sedimentology (i.e. sediment transport) a semi-quantitative approach has been undertaken using catchment modeling. Specifically, a model was established to estimate natural background flows (i.e. rainfall-runoff processes) and the load of total suspended solids (TSS) across the study area catchments for current land use conditions.

Information on sediment transport is relevant to water quality and aquatic biodiversity assessments in the context of likely changes in the aquatic environment as a result of the Project. However, as the Purari River is known to discharge high volumes of sediment on an annual basis, the overall sediment transport impact of the Project is expected to be small. For this reason, semi-quantitative modeling was preferred over development of a detailed receiving water quality model.

Specifically, the catchment model was used to inform estimation of rainfall-runoff and sediment loads of the study catchment, through the following:

- Simulation of runoff volume and constituent load/concentrations for major sub-catchments contributing to the Purari River.
- Estimation of the contribution of TSS from both point and non-point (diffuse) sources occurring within the study catchment and additional contributions to streamflow in major watercourses and the change to flow regime components (e.g. timing, frequency, magnitude, duration).
- Estimation of flow volume and TSS load/concentration changes at discrete locations downstream of the project development area.

A Power Function for constituent (i.e. TSS) generation at a catchment scale was adopted for the study. This method fits a rating curve to describe the relationship between constituent generation/load and discharge. The function is fitted using parameters including low-flow TSS concentrations, the maximum concentration of TSS and the slope of the curve. The daily TSS load is calculated as the product of daily flow and the concentration at that flow derived from the rating curve for each functional unit.

3 Data Sources

Table 3-1 summarizes the data sources that were used for the purposes of modeling described in this report.

Table 3-1 Data Sources Utilized for Modeling

Area	Data source	Description
Rainfall	Papua New Guinea Flood Estimation Manual (FEM – SMEC, 1990)	Provides design rainfall
	Bureau of Water Resources gauging station data: • Purari station (712400) • Asaro station (704300) • Chimbu station (705090)	 1962-1989 rainfall 1961-1976 rainfall 1971-1990 rainfall
	PRL-15 rainfall gauge data: • Herd Base • Antelope 3	 Aug-2015 to Dec-2016 rainfall Jan-2104 to Dec-2016 rainfall
	Australian Rainfall and Runoff online data hub	Design rainfall temporal patterns
	Australian Bureau of Meteorology 2016 Rainfall IFD Data System	Design rainfall
Streamflow	Bureau of Water Resources gauging station data: • Purari station (712400) • Waghi station (703880)	 1970-1991 streamflow 1967-1980 streamflow
	Published data by Pickup and Chewings (1983)	Monthly flows for Purari and Aure rivers
Topography	LiDAR elevation data (ERIAS Group): • DEM_001_170130_1m_PRL_15 • DEM_003_170130_2m_ExportCorridor	 1 m grid resolution elevation data (PRL-15) 2 m grid resolution elevation data (pipeline corridor)
	Shuttle Radar Telemetry Mission (SRTM) elevation data	30 m grid resolution elevation data
Sediment transport	Published data by Pickup (1983)	Sediment input for Purari River (at Wabo) and Aure River

The majority of the data was supplied to BMT WBM by ERIAS Group, with the exception of the data from the PNG Flood Estimation Manual and that obtained by BMT WBM, through online data sources.

The LiDAR ground elevation data is highly accurate and of a fine resolution. However, it does not provide bed elevations within channels/depressions that contain water as LiDAR sensing techniques cannot penetrate deep water. It also can be potentially inaccurate in areas of very

dense vegetation. As such the level of the main Purari River channel in the LiDAR data set provided was set at 4.8 m for the entire length within the vicinity of Herd Base (i.e. 4.8 m above the 0 m datum/'bottom' of the LiDAR data set). The 0 m datum of the LiDAR is assumed to be set to Papua New Guinea mean sea level.

The SRTM data has is a 30m grid resolution with a vertical accuracy of ±16 m it has a horizontal accuracy of SRTM data were to be sampled over a grid of 1 arc-second by 1 arc-second (approximately 30 m by 30 m), with linear vertical absolute height error of less than 16 m, linear vertical relative height error of less than 10 m.

While some bathymetric data for the Purari River was available (i.e. two cross-sections near Herd Base and mapping of >5 m and <5 m depth between coast and Wabo) this was not considered appropriate for modeling purposes. Detailed bathymetry is required at multiple locations and/or for long stretches of the river for modeling.

4 Modeling and Assessment Methodology

4.1 Hydrological Assessment

The hydrological modeling consisted of a number of activities, intended to provide sufficient input for hydraulic assessments (see Section 4.2) based on the 10, 50 and 100 year Average Recurrence Interval (ARI) events. These activities, described in more detail below, consisted of the following:

- Delineation of sub-catchments for the Purari, Pie and Era river catchments
- Analysis of rainfall patterns for each sub-catchment
- Site-based and regional flood frequency assessment for a key flow gauge in order to provide data sources for partial 'validation' of the URBS hydrological model
- Development of the URBS hydrological model.

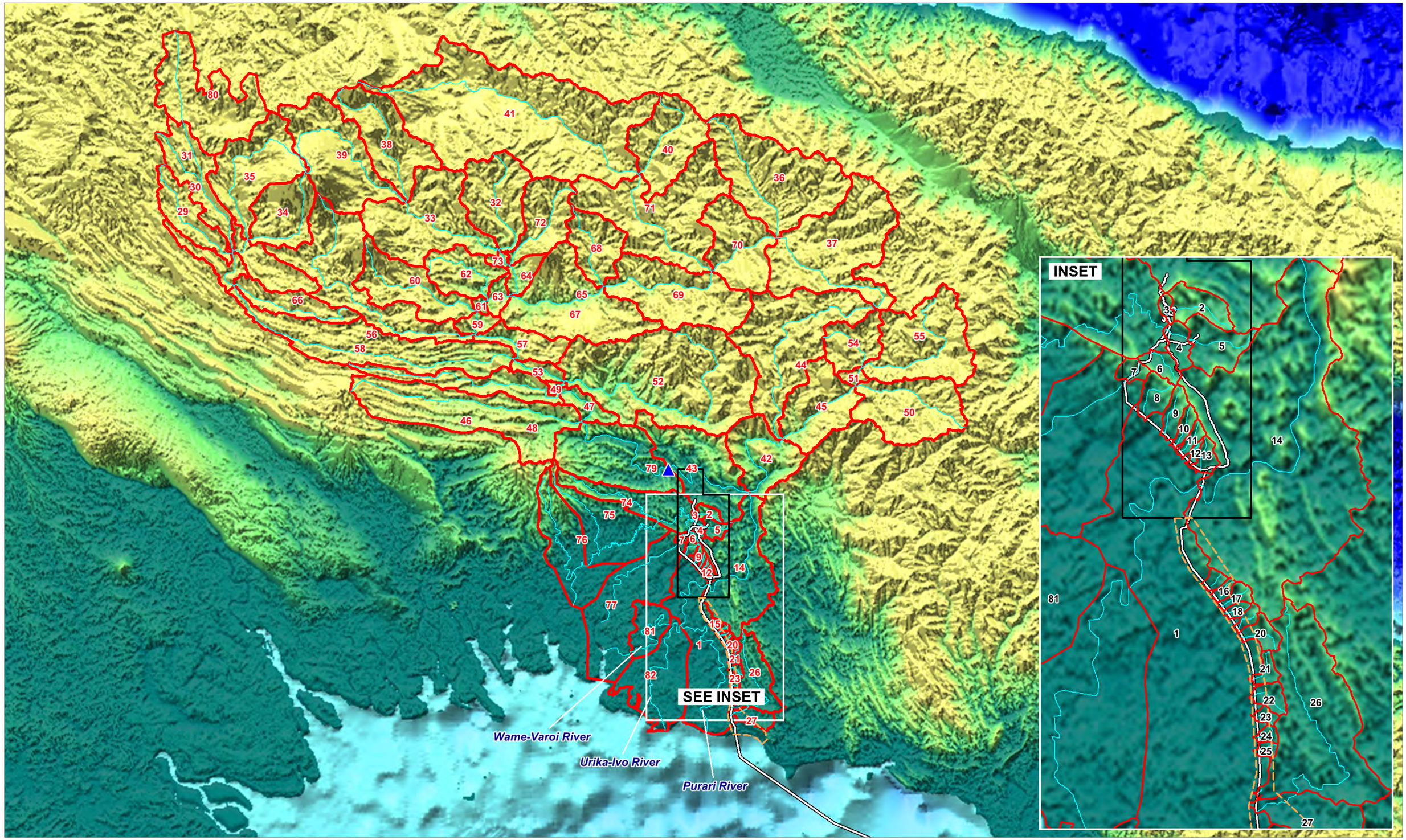
4.1.1 Catchment Description and Delineation

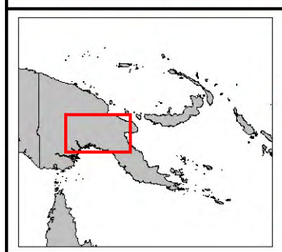
NOTE: While it is noted that Project infrastructure routes have not been finalized, catchment delineation required adoption of indicative Project infrastructure layers and corridors in order to identify the areas most relevant to the baseline assessment.

The catchment delineation for the study area was undertaken using SRTM data as this is the only topographic data that covers all the catchments in potential Project infrastructure areas. The resolution of the SRTM and its potential inaccuracies can lead to some issues with catchment delineation. As such, this limited the minimum catchment size that could be reasonably delineated.

The SRTM data was input to CatchmentSIM. CatchmentSIM is a software package used for hydrologic analysis of terrain including mapping catchments and flow paths as well as integration with hydrologic models. The initial catchment delineation provided the major catchments of the Purari, Pie and Era Rivers. These catchments were then subdivided based on proposed trunkline and onshore export pipeline corridors and further sub-divided upstream into numerous sub-catchments so as to better represent the changing characteristics of the different parts of the catchment. Figure 4-1 provides the sub-catchment delineation for the study area.

CatchmentSIM provides the ability to export the catchment and sub-catchment parameters such as area, slope, stream length, etc. in the format of numerous hydrologic modeling packages. This function was utilized to provide the model files for the hydrologic modeling software Unified River Basin Simulator (URBS).





LEGEND

- PRL-15 Boundary
- Sub-catchments
- Onshore Export Pipeline Corridor
- Gauging Station
- Waterways
- Trunkline Infrastructure Options

-1000 -750 -500 -250 0 250 500 750 >1000

Elevation (m)

Title:

Study Area Sub-catchments

Figure: 4-1

Rev: A

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Scale - Inset

0 25 50km
Scale - Main Map

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4.1.2 Intensity Frequency Durations

Section 4 of the PNG Flood Estimation Manual (SMEC, 1990) provides guidance on determining design rainfall. It provides a comprehensive methodology to determine rainfall depth, intensities and temporal patterns for Average Recurrence Intervals (ARIs) from 2 year to 100 yr, storm durations from 6 minute to 24 hours with the corresponding temporal patterns.

This study has relied heavily on the estimation of design rainfall derived from the PNG Flood Estimation Manual. The existing measured rainfall data sets that were available were fragmented (large gaps between records) and contained no sub-daily records.

The first step in determining the design rainfall is to determine the point daily rainfall values for the 2 and 100 year annual series return intervals (P_2 and P_{100}) for each sub-catchment. This was achieved through the digitizing of Figures 3a and 4a (Appendix A and B) from the PNG Flood Estimation Manual to geographical reference points, as shown in Figure 4-2 and Figure 4-3. The results of this are shown in Table 4-1.

Based on these values, it can be seen that the rainfall varies greatly across the study area with the highest daily rainfall totals nearest the coast (Gauge 60002 P_2 208 mm and Gauge 60003 P_{100} 440 mm) with daily totals decreasing with distance inland (Gauge 5003 P_2 44 mm and P_{100} 80 mm).

These points were then gridded using the 'Nearest Neighbor' algorithm in MapInfo, the software package used for GIS components of this study. The sub-catchment polygons were then used to derive the mean P_2 and P_{100} values for each sub-catchment.

The daily rainfall (P_t) was calculated using the following formula, with the calculated P_t for all catchments and return periods presented in Appendix B;

$$P_t = P_2 + KP_t(P_{100} - P_2)$$

Where $KP_5 = 0.27$

$KP_{10} = 0.45$

$KP_{20} = 0.62$

$KP_{50} = 0.83$

The point total depth ($D_{T,t}$) was calculated for all catchments, storm durations and return periods using the rainfall ratios ($D_{T,t}/P_T$) (shown in Table 4-2) and the below formula;

$$D_{T,t} = \left(\frac{D_{T,t}}{P_T}\right) * P_T$$

Rainfall ratios beyond 24 hours were derived from ARR 2016 rainfall depths from Cape York Queensland. A single ratio for all depths was applied to the durations beyond 24 hours. The temporal patterns for the storms longer than 24 hours were also from the ARR 2016 temporal patterns for Cape York Queensland. The areal reduction factor (KA) was applied to all point total depths for each sub-catchment based on their catchment area and Figure 4-4 for all catchments. Intensity frequency duration tables were developed for each sub-catchment and the IFD table for sub-catchment 20 has been provided as an example in Table 4-3.

Table 4-1 PNG Flood Estimation Manual P_2 and P_{100} Gauge Values

Gauge Number	P_2 (mm)	P_{100} (mm)	Gauge Number	P_2 (mm)	P_{100} (mm)
60010	168	340	75004	65	120
70001	80	160	75006	56	100
70009	107	210	75005	73	130
70015	113	230	75010	56	100
70008	71	140	70003	79	160
70005	69	140	70007	103	210
70013	81	160	60016	91	180
5003	44	80	60018	87	210
5004	55	100	70002	66	130
5002	48	90	10005	118	210
5012	59	110	10006	71	130
5010	57	100	10008	90	180
75023	65	120	25004	71	130
75001	69	120	25006	68	120
5001	81	150	25008	76	140
60001	167	423	25002	61	110
60003	175	440	25003	64	120
60007	141	350	25001	64	116
60002	208	328	25013	67	120
60011	98	200	25035	69	120
90004	84	150	25034	69	120
90009	71	130	25043	79	140
90002	64	120	25023	49	90
90001	66	120	30011	68	120
90008	55	100	30014	63	130

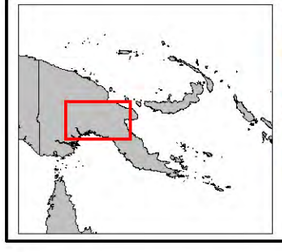
Table 4-2 Short duration Rainfall Ratios (D_t/P_t)

Duration (t) hours	P2 (mm)														
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180+
0.1	0.15	0.15	0.15	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.11	0.11	0.11	0.1	0.1
0.25	0.35	0.34	0.33	0.32	0.31	0.29	0.28	0.27	0.26	0.25	0.24	0.22	0.21	0.2	0.19
0.5	0.48	0.46	0.45	0.43	0.41	0.39	0.38	0.36	0.34	0.33	0.31	0.29	0.27	0.26	0.24
1	0.63	0.61	0.58	0.56	0.54	0.52	0.5	0.48	0.46	0.44	0.42	0.4	0.38	0.36	0.34
1.5	0.7	0.68	0.66	0.64	0.62	0.6	0.59	0.57	0.55	0.53	0.51	0.49	0.47	0.46	0.44
2	0.76	0.74	0.73	0.71	0.69	0.67	0.66	0.64	0.62	0.6	0.58	0.57	0.55	0.53	0.51
2.5	0.8	0.78	0.77	0.75	0.73	0.72	0.7	0.68	0.67	0.65	0.63	0.62	0.6	0.58	0.57
3	0.84	0.83	0.81	0.79	0.78	0.76	0.75	0.73	0.71	0.7	0.68	0.67	0.65	0.63	0.62
4	0.88	0.86	0.85	0.83	0.82	0.81	0.79	0.78	0.76	0.75	0.74	0.72	0.71	0.7	0.68
5	0.9	0.89	0.88	0.87	0.85	0.84	0.83	0.82	0.8	0.79	0.78	0.77	0.76	0.74	0.73
6	0.92	0.91	0.9	0.89	0.88	0.87	0.86	0.85	0.84	0.83	0.82	0.8	0.79	0.78	0.77
7	0.94	0.93	0.92	0.91	0.9	0.89	0.88	0.87	0.86	0.86	0.85	0.84	0.83	0.82	0.81
8	0.96	0.95	0.94	0.93	0.92	0.91	0.91	0.9	0.89	0.88	0.87	0.86	0.85	0.85	0.84
9	0.97	0.96	0.96	0.95	0.94	0.93	0.93	0.92	0.91	0.9	0.89	0.89	0.88	0.87	0.86
10	0.98	0.98	0.97	0.96	0.96	0.95	0.94	0.94	0.93	0.92	0.91	0.91	0.9	0.89	0.89
11	1	0.99	0.98	0.98	0.97	0.96	0.96	0.95	0.95	0.94	0.93	0.93	0.92	0.91	0.91
12	1.01	1	0.99	0.99	0.98	0.98	0.97	0.97	0.96	0.96	0.95	0.94	0.94	0.93	0.93
14	1.04	1.04	1.03	1.02	1.02	1.01	1.01	1	0.99	0.99	0.98	0.98	0.97	0.97	0.96
16	1.06	1.06	1.05	1.04	1.04	1.03	1.03	1.02	1.01	1.01	1	1	0.99	0.98	0.98
18	1.09	1.09	1.08	1.07	1.07	1.06	1.05	1.05	1.04	1.04	1.03	1.02	1.02	1.01	1.01
20	1.12	1.11	1.1	1.1	1.09	1.09	1.08	1.07	1.07	1.06	1.05	1.05	1.04	1.04	1.03
22	1.15	1.14	1.13	1.13	1.12	1.11	1.11	1.1	1.1	1.09	1.08	1.08	1.07	1.06	1.06
24	1.17	1.16	1.15	1.15	1.14	1.13	1.13	1.12	1.12	1.11	1.1	1.1	1.09	1.08	1.08

Table 4-3 Sub-Catchment 20 Intensity Frequency Duration Table

Duration (minutes)	ARI rainfall intensity (mm/h)						
	2 yr	5 yr	10 yr	20 yr	25 yr	50 yr	100 yr
6	164.9	228.4	270.8	310.7	322.5	360.1	400.1
15	131.9	182.7	216.6	248.6	258.0	288.1	320.1
30	85.7	118.8	140.8	161.6	167.7	187.3	208.1
60	59.4	82.2	97.5	111.9	116.1	129.6	144.0
90	50.6	70.0	83.0	95.3	98.9	110.4	122.7
120	43.7	60.5	71.7	82.3	85.5	95.4	106.0
150	38.3	53.0	62.8	72.1	74.8	83.6	92.8
180	34.6	48.0	56.9	65.3	67.7	75.6	84.0
240	28.9	40.0	47.4	54.4	56.4	63.0	70.0
300	24.4	33.8	40.1	46.0	47.7	53.3	59.2
360	21.4	29.7	35.2	40.4	41.9	46.8	52.0
420	19.3	26.8	31.7	36.4	37.8	42.2	46.9
480	17.5	24.3	28.8	33.0	34.3	38.3	42.5
540	15.9	22.1	26.2	30.0	31.2	34.8	38.7
600	14.7	20.3	24.1	27.7	28.7	32.1	35.6
660	13.6	18.9	22.4	25.7	26.7	29.8	33.1
720	12.8	17.7	21.0	24.1	25.0	27.9	31.0
840	11.7	16.2	19.1	22.0	22.8	25.5	28.3
960	10.3	14.3	16.9	19.4	20.2	22.5	25.0
1,080	9.4	13.1	15.5	17.8	18.5	20.6	22.9
1,200	8.8	12.1	14.4	16.5	17.1	19.1	21.2
1,320	8.1	11.2	13.3	15.3	15.9	17.7	19.7
1,440	7.6	10.5	12.4	14.3	14.8	16.5	18.4
2,160	5.5	7.7	9.1	10.4	10.8	12.1	13.4
2,880	4.4	6.1	7.3	8.3	8.6	9.7	10.7
4,320	3.2	4.5	5.3	6.1	6.3	7.0	7.8
5,760	2.6	3.6	4.2	4.9	5.0	5.6	6.3
7,200	2.2	3.0	3.6	4.1	4.2	4.7	5.3
8,640	1.9	2.6	3.1	3.5	3.7	4.1	4.6
11,520	1.5	2.1	2.5	2.8	2.9	3.3	3.6
14,400	1.3	1.8	2.1	2.4	2.5	2.8	3.1

05001 81
05012 59
05002 48
05004 55
05010 57
75001 69
75005 73
75006 56
10005 118
70002 66
75023 65
75010 56
75004 65
90001 66
90008 55
10008 90
05003 44
90002 64
25002 61
25008 76
25003 64
25001 64
70005 69
70008 71
90009 71
25006 68
70003 79
70007 103
25004 71
70013 81
25013 67
70015 113
90004 84
30011 68
25035 69
25034 69
70009 107
70001 80
25043 79
25023 49
60010 168
60011 98
30014 63
60002 208
60016 91
60007 141
60003 175
60001 167
60018 87



LEGEND

Sub-catchments

Proposed Pipeline Corridor

Waterways

Rainfall Stations labelled with Station Number Rainfall

50 100 150 200 250 300 350 >400

Rainfall (mm)

Title:

Point Daily Rainfall with an annual series return period of 2 years points and Grid

Figure: 4-2

Rev: A

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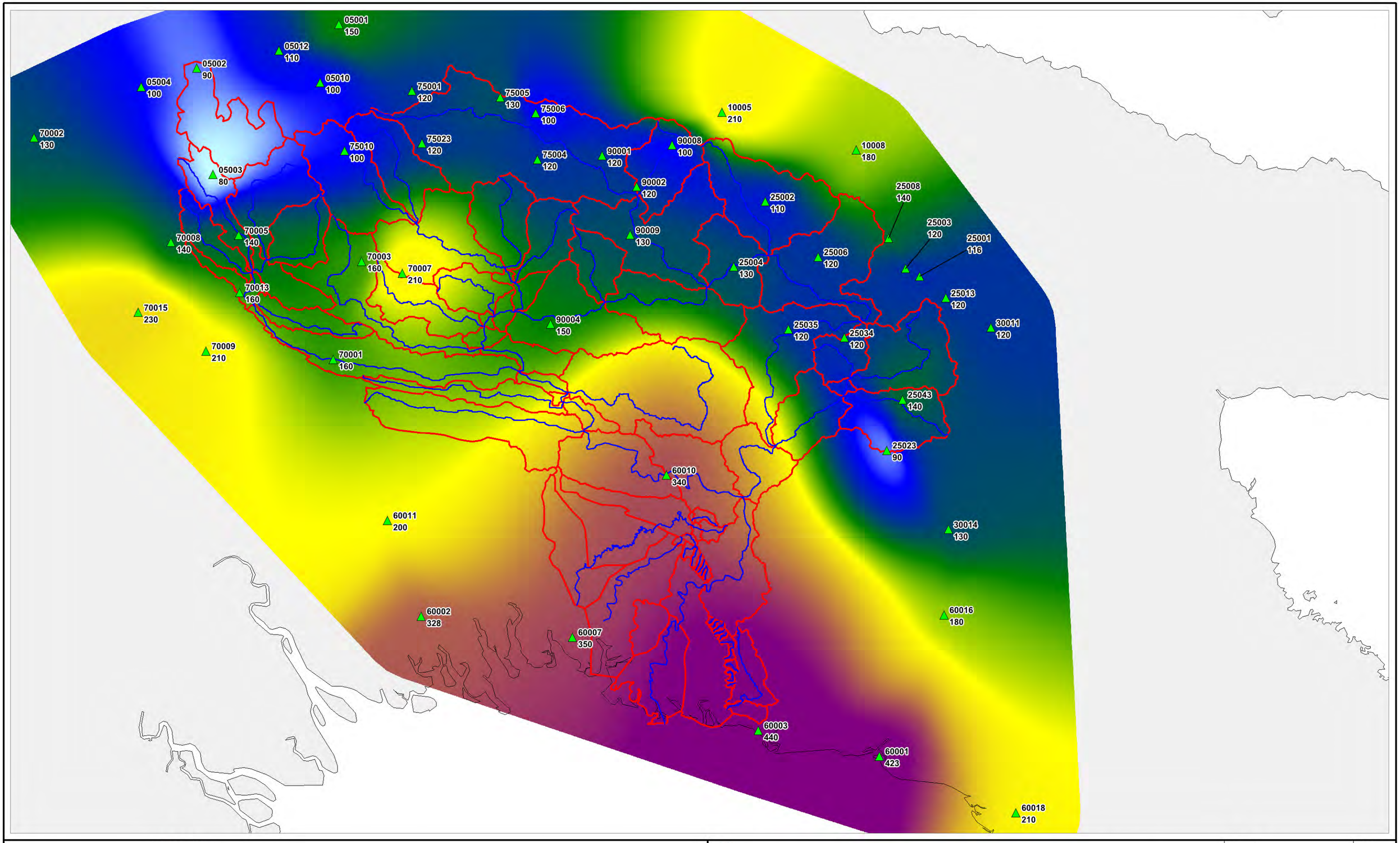
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Approx. Scale

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LEGEND

- Sub-catchments
- Proposed Pipeline Corridor
- Waterways
- Rainfall Stations labelled with Station Number Rainfall

50 100 150 200 250 300 350 >400

Rainfall (mm)

Title:

Point Daily Rainfall with an annual series return period of 100 years points and Grid

Figure: 4-3

Rev: A

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Approx. Scale

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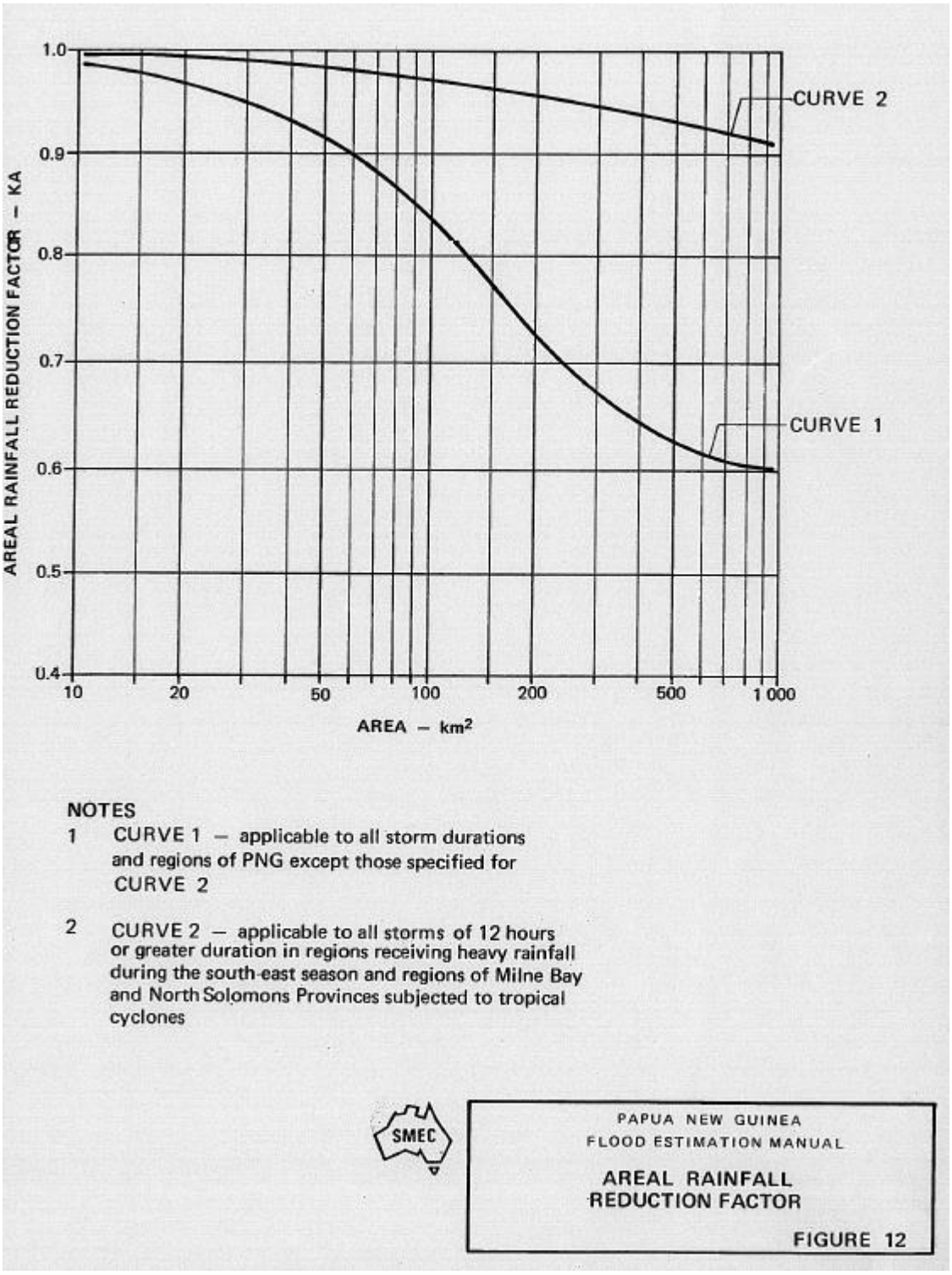


Figure 4-4 PNG Flood Estimation Manual Figure 12 Areal Rainfall Reduction Factor

4.1.3 Flood Frequency Assessments

4.1.3.1 Flike Flood Frequency Analysis

A flood frequency analysis (FFA) was undertaken for the stream gauge upstream of Wabo Creek on the Purari River. The data included river level measurements that were taken from 1970 through to 1991 (22 years). The corresponding derived flow records are presented in Table 4-4. This data was input to the Flike Software to undertake the FFA.

Flike is an extreme value analysis package that calculates the probability of flood events based on historical records. It has been created for flood frequency analysis, but can be applied to any extreme value analysis. Developed by Professor George Kuczera from the School of Civil Engineering at the University of Newcastle Australia, Flike is compliant with the recent major revision of industry guidelines for flood estimation, documented in Australian Rainfall and Runoff (ARR, 2016).

Table 4-4 Purari River Upstream of Wabo Creek (Purari Gauge Station (712400)) Peak Annual Flow with Flike estimate of ARI

Year	Peak annual flow (m^3/s)	Rank	ARI plotting position (years)
1970	7,120	11	2.1
1971	6,450	15	1.5
1972	6,360	16	1.4
1973	7,240	9	2.6
1974	4,640	19	1.2
1975	7,450	5	4.8
1976	7,560	4	6.2
1977	8,270	2	13.9
1978	5,370	18	1.3
1979	5,510	17	1.3
1980	7,410	6	4.0
1981	6,580	14	1.6
1982	3,070	20	1.1
1983	6,870	12	1.9
1984	7,290	8	2.9
1985	11,340	1	37.0
1986	7,190	10	2.3
1987	6,620	13	1.8
1988	7,600	3	8.5
1989	7,360	7	3.4
1990	1,190	22	1.0
1991	2,760	21	1.1

The results of the Log Pearson III analysis of the data in Table 4-4 produced the peak flow ARI estimate in Table 4-5 and plotted in Figure 4-5. The results show that there is a relatively smaller difference in the peak flow of the more extreme flow events. This is due to the small sample number of events that were used in the analysis. This is shown by the widening range in the Monte Carlo upper and lower peak flow estimates.

Table 4-5 Flike ARI Flow Estimates- Purari Gauge Station (712400)

ARI (years)	Peak flow (m^3/s)		
	Estimated Flow	Monte Carlo	
		Lower limit Flow	Upper limit Flow
1.001	790	230	1,620
1.01	1,540	700	2,500
1.1	3,130	2,100	4,100
1.25	4,190	3,180	5,140
1.5	5,170	4,250	6,150
1.75	5,810	4,913	6,830
2	6,280	5,400	7,310
5	8,490	7,580	9,660
10	9,580	8,600	10,880
20	10,410	9,374	11,980
50	11,240	10,130	13,280
100	11,720	10,540	14,180
200	12,110	10,850	14,950
500	12,530	11,160	15,920
1000	12,770	11,310	16,620

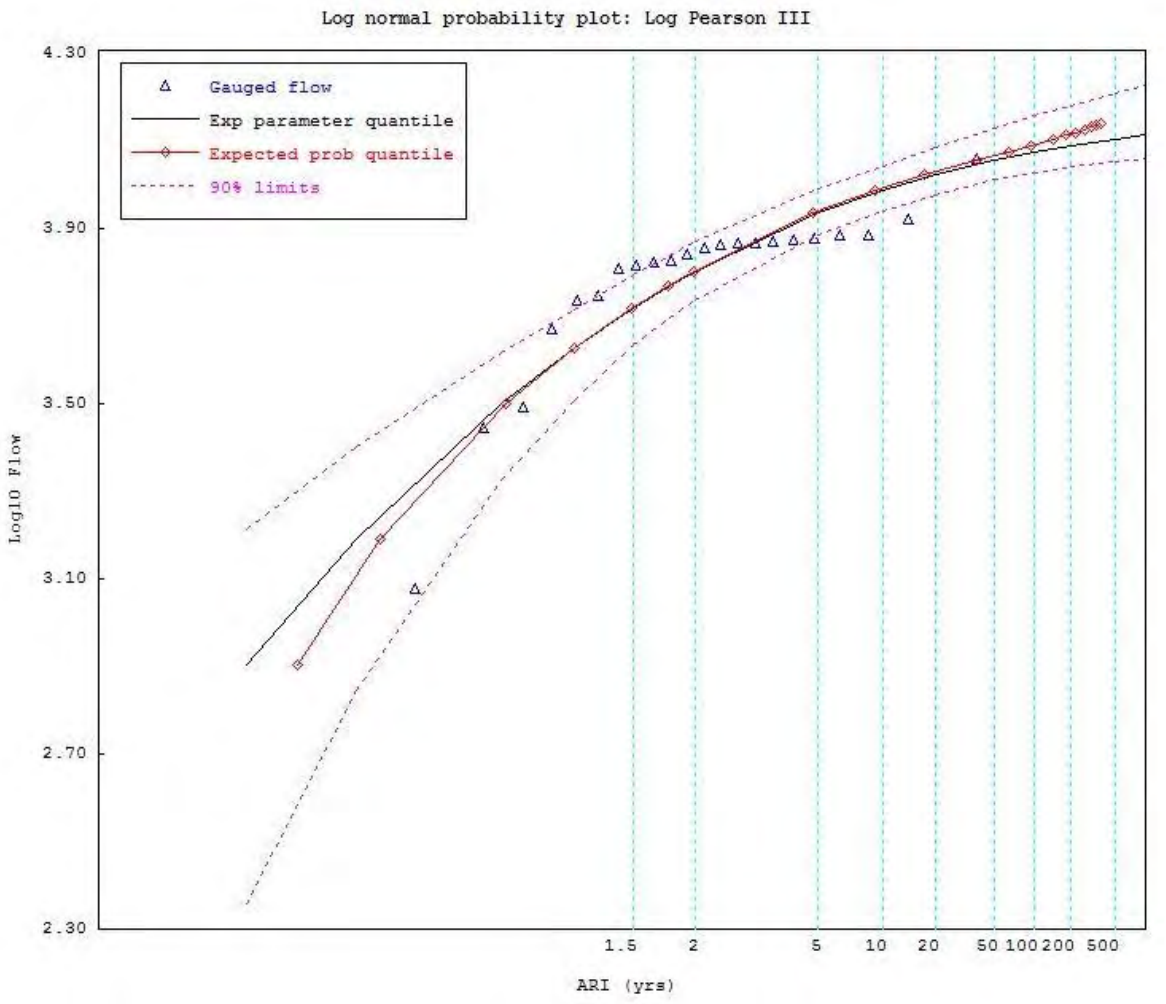


Figure 4-5 Flike ARI Peak Flow Estimates- Purari Gauge Station (712400)

4.1.3.2 Regional Flood Frequency Assessment

To provide some additional validation of the hydrology model and the FFA, an assessment using the PNG Flood Estimation Manual - Regional Flood Frequency (RFF) Method was undertaken for the catchment to the Purari River upstream of Wabo Creek (Gauge 712400). Section 5 of the PNG Flood Estimation Manual describes the RFF Method used to determine peak flow for a number of ARI events. An overview of the method used and results obtained is provided below.

The method uses three parameters for the estimation of peak flood flows. These are Area (km^2), P_2 (mm) and slope (m/km). Other factors are used to assign/define 'normality' of the catchment which include Swamp, Shape and Karst.

The values for the above listed parameters determined for the catchment are provided in Table 4-6.

Table 4-6 Regional Flood Frequency Parameter Values for the Purari River Catchment to Purari River Station Gauge 712400

Parameter	Estimated value
Area	25,067 km^2
P_2	81.9 mm
Slope	2.5 m/km
Swamp	1
Shape	1.21
Karst	1
Z	174.2 km
Swamp Adjustment factor	1

The other return period (T) flood discharges in Table 4-7 are calculated using Equation 4.6 of the PNG Flood Estimation Manual $Q_T = Q_2 + KQ_T*(Q_{100}-Q_2)$, where

$KQ_5 = 0.27$

$KQ_{10} = 0.45$

$KQ_{20} = 0.62$

$KQ_{50} = 0.83$

The PNG Flood Estimation Manual states that these are standardized estimates of the peak flow falling within the standard error ranges provided in Table 4-8.

Table 4-7 Regional Flood Frequency Peak Flow Estimates - Purari River Station (712400)

ARI (years)	Peak flow (m^3/s)
2	5,310#
5	5,810
10	6,140
20	6,450
50	6,840
100	7,510*

Calculated using Equation 4.2 PNG Flood Estimation Manual $Q_2 = 4.0*AREA^{\wedge 0.71}*KS$

* Calculated using Equation 4.5 PNG Flood Estimation Manual $Q_{100} = 13.4*AREA^{\wedge 0.62}$

Table 4-8 Standard Errors of the Regional Flood Frequency Method

ARI (years)	Standard error
2	+80%, -30%
5	+95%, -35%
10	+100%, -40%
20	+110%, -40%
50	+130%, -45%
100	+150%, -50%

Comparison of peak flow estimates produced using the Flike FFA method with the RFF is shown in Table 4-9. As shown, the RFF tends to produce much lower peak flood flows, although they are within the stated standard error of the Flike FFA peak flows.

Table 4-9 Comparison of Regional Flood Frequency and Flike Flood Frequency Peak Flow Estimates

ARI (years)	Regional flood frequency peak flow (m^3/s)	Flike flood frequency peak flow (m^3/s)	Difference (m^3/s)	Difference (% of RFF)
2	5,310	6,280	970	18%
5	5,810	8,490	2,680	46%
10	6,140	9,580	3,440	56%
20	6,450	10,410	3,960	61%
50	6,840	11,240	4,400	64%
100	7,510	11,720	4,210	56%

4.1.4 URBS Hydrological Model

Unified River Basin Simulator (URBS) is a widely-recognized hydrologic software program used for undertaking rainfall-runoff simulations to produce flood flow hydrographs. It is referenced in *Australian Rainfall and Runoff: A Guide to Flood Estimation* (ARR, 1987 and 2016). The PNG Flood Estimation Manual has been based on and refers to ARR for guidance in flood estimation.

"URBS is a runoff-routing networked model of sub-catchments based on centroidal inflows. Two runoff routing models are available to describe catchment and channel storage routing behavior. These are the URBS Basic and Split routing models.

The Basic model is a simple model where stream length (or derivative) is assumed to be representative of both catchment and channel storage. The Split Model separates the channel and catchment storage components of each sub-catchment for routing purposes. Irrespective of the model used, each storage component is conceptually represented as a non-linear storage." (Carrol, 2012).

As described in Section 4, CatchmentSIM was used to delineate the sub-catchments to be considered by the URBS model. The model comprises 80 sub-catchments that incorporate the Purari River, Pie River and Era River catchments. There is greatest sub-catchment delineation

along proposed trunkline and onshore export pipeline corridors as these are the areas of greatest importance to this assessment.

The PNG Flood Estimation Manual recommends that the loss values in Table 4-10 be used for design storm runoff routing. Table 4-10 also includes the adopted loss parameters that were chosen as a result of a validation against the Purari River gauge upstream of Wabo Creek. The results of the comparison are shown in Table 4-11.

The URBS model was able to achieve a good match with the 100 year ARI event using the suggested losses, but was unable to replicate similar flows for the 10 year and 50 year ARI events. It is reasonable to expect longer duration events, such as the ones that would provide the critical duration at the Purari River gauge upstream of Wabo Creek, would occur when the catchment is already wet. As such, the losses would likely be lower for these events. For this reason, the continuing losses were reduced and the URBS Alpha and Beta parameters were adjusted to achieve a better match for the 10, 50 and 100 year ARI events when compared to the FFA and RFF estimates for those events. For locations with smaller upstream catchments, the recommended loss parameters were adopted as these catchments require short duration events where these losses have little effect on runoff generation.

Table 4-10 Recommended and Adopted Loss Parameters for use with Design Storms (PNG FEM)

Return period (years)	Initial loss (mm)	Continuing losses (mm/h)
2	5-10	3.0 – 3.5
10	0 -10	2.5 – 3.0
100	0	2.5
Adopted (10, 50 and 100)	0	0.5 main Purari River model 2.5 for pipeline crossings with small upstream catchments

Table 4-11 Comparison of the Estimated Peak Flows at the Purari River gauge upstream of Wabo Creek

ARI (years)	Regional flood frequency peak flow (m^3/s)	Flike flood frequency peak flow (m^3/s)	URBS peak flow
10	6,140	9,580	6,620
50	6,840	11,240	8,920
100	7,510	11,720	9,980

The other parameters that were adopted for the URBS model are as follows

- Alpha (α) - 0.008 – as channel slope (Sc) was used
- Beta (β) - 7
- M - 0.8

The hydrographs that were created from the URBS model were applied to the TUFLOW model as the inflows. An assessment of the peak flows from the URBS model has shown that the smaller sub-catchments have a critical duration of 6 hours. Only the catchments that provide flows to the models S10 (Purari River/Herd Base) model and S20 required longer critical durations, 72 hours for S10 and 36 hours for S20.

4.2 Hydraulic Modeling

The proposed trunkline and onshore export pipeline corridors cross numerous waterways across the study area. Hydraulic modeling of 20 of these waterways was undertaken as part of this assessment to produce estimates of flow behavior. The locations were chosen based on the size of the upstream catchment.

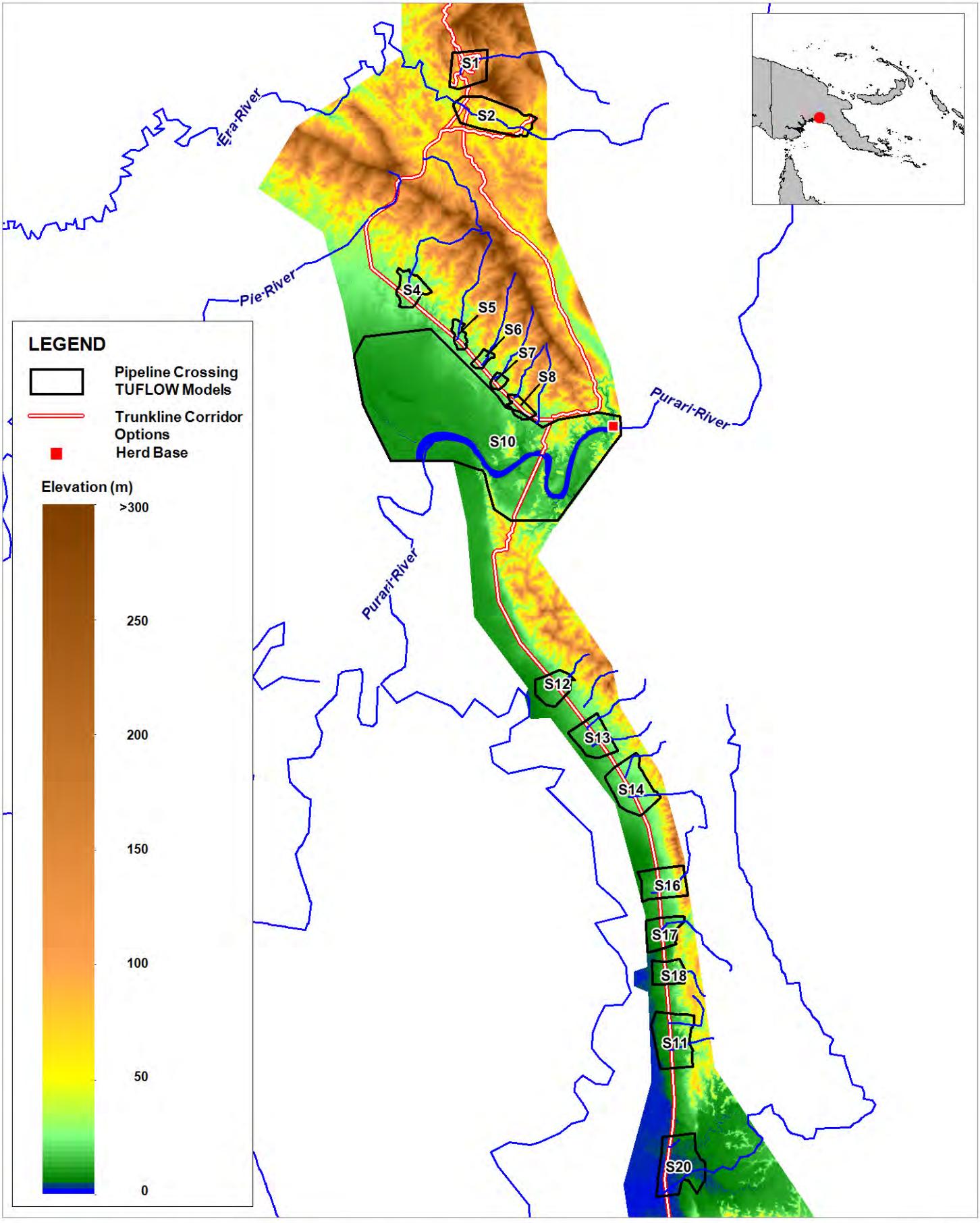
During the development of the hydraulic models it was determined that there was the potential for flow paths from a number of waterways to interact in larger flows. Hence, it was decided that some of the hydraulic models should be joined to better reflect these potential interactions and to avoid model boundary effects (such as “glass-walling”). With these considerations, a total of sixteen TUFLOW models have been set up to assess the twenty sub-catchments. These TUFLOW models are named S1 to S20 for convenience, with their locations shown in Figure 4-6.

4.2.1 Model Development

TUFLOW is a computer program for simulating depth-averaged, one and two-dimensional free-surface flows such as occurs from floods and tides, with the 2D solution occurring over a regular grid of square elements. TUFLOW was originally developed for modeling two-dimensional (2D) flows, and stands for Two-dimensional Unsteady FLOW.

TUFLOW incorporates two grid based solvers; a CPU based second order semi-implicit solution often referred to as TUFLOW Classic, and a heavily parallelized first order explicit solver built for speed referred to as TUFLOW GPU.TUFLOW offers two 2D numerical schemes: a CPU based 2nd order implicit scheme, and the TUFLOW GPU module that value adds as a heavily parallelized 1st order rapid solver specifically designed for high end graphic cards (GPUs) that can reduce run-times by one to two orders of magnitude. This study utilizes the TUFLOW GPU model solver.

The sixteen TUFLOW models that have been developed for this study have all been based on a 5m grid with ground elevation derived from the LiDAR DEMs supplied by ERIAS Group. The only exception to this is the S10 Purari River model which has a 10m grid due to the large extent of the model. The model extents are shown in Figure 4-6.



Title:

TUFLOW Model Extents within the Study Area

Figure: **4-6**

Rev: **A**

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0 5 10km

Approx. Scale

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As discussed in Section 2, the topographic data relied on to inform the development of the hydraulic models is LiDAR data in which there is no definition of ground surface elevation below any water surface. That is, the elevation data within the channel of some watercourses is unavailable, as the LiDAR data simply reflects the elevation of the water surface at the time at which the LiDAR data was collected. This can have a significant impact on the accuracy of hydraulic model results for flow events that are predominately contained within the channel, where the channel conveys a significant proportion of the flow volume. This is the case for the Purari River, for which channel shape and depth below the water surface level is not known. This has resulted in the entire Purari River channel within the extent of the LiDAR dataset being assigned the same elevation 4.8 m (representing the water level in the river when LiDAR was flown). As no bathymetry DEM or survey has been supplied at this stage of the assessment, it has been necessary to artificially lower the channel within the S10 Purari River hydraulic model to provide a very rough estimate of channel depth and to allow water to flow towards the downstream extent of the model.

Each TUFLOW model has had land use (hydraulic roughness) areas digitized based on aerial photography as provided in Table 4-12. These Manning's n values are typical industry standard values.

Table 4-12 Land Use Hydraulic Roughness Values

Land use	Manning's n
Trees	0.15
Creek	0.08
Buildings	0.3
Water	0.03
Roads	0.02
Med Veg	0.08

All downstream boundaries for the TUFLOW hydraulic models have been set to normal depth; these have been digitized at the downstream extent of the individual models with some models requiring multiple downstream boundaries due to their complex flow pattern. The downstream boundaries have been set sufficiently far enough downstream of the pipeline crossing so as to not incur any boundary effect. The downstream boundary of the S10 Purari River model has been set at the limit of the available LiDAR data. This is not sufficiently downstream of the PRL-15 oxbow wetlands and ideally this model should be extended further downstream. It was initially expected that the SRTM data could be used to extend the model in this direction. However, comparison of the ground elevations between the LiDAR and the SRTM data indicated that the difference in elevations was too great to allow the use of the SRTM data for this purpose. The SRTM elevations have been found to be higher than the LiDAR data by approximately 10m around the channel and 30m on the floodplain and hills at the junction of the two data sets. This significant difference is shown in Figure 4-7.

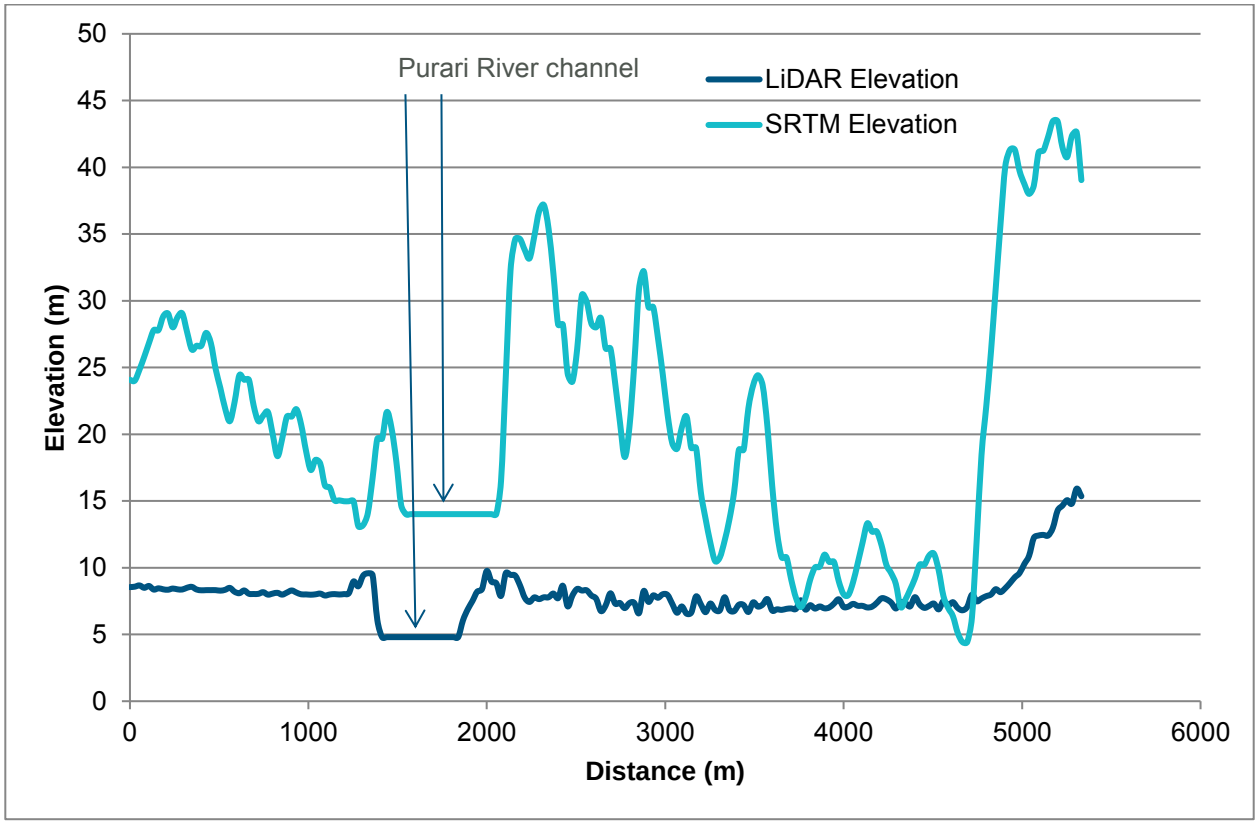
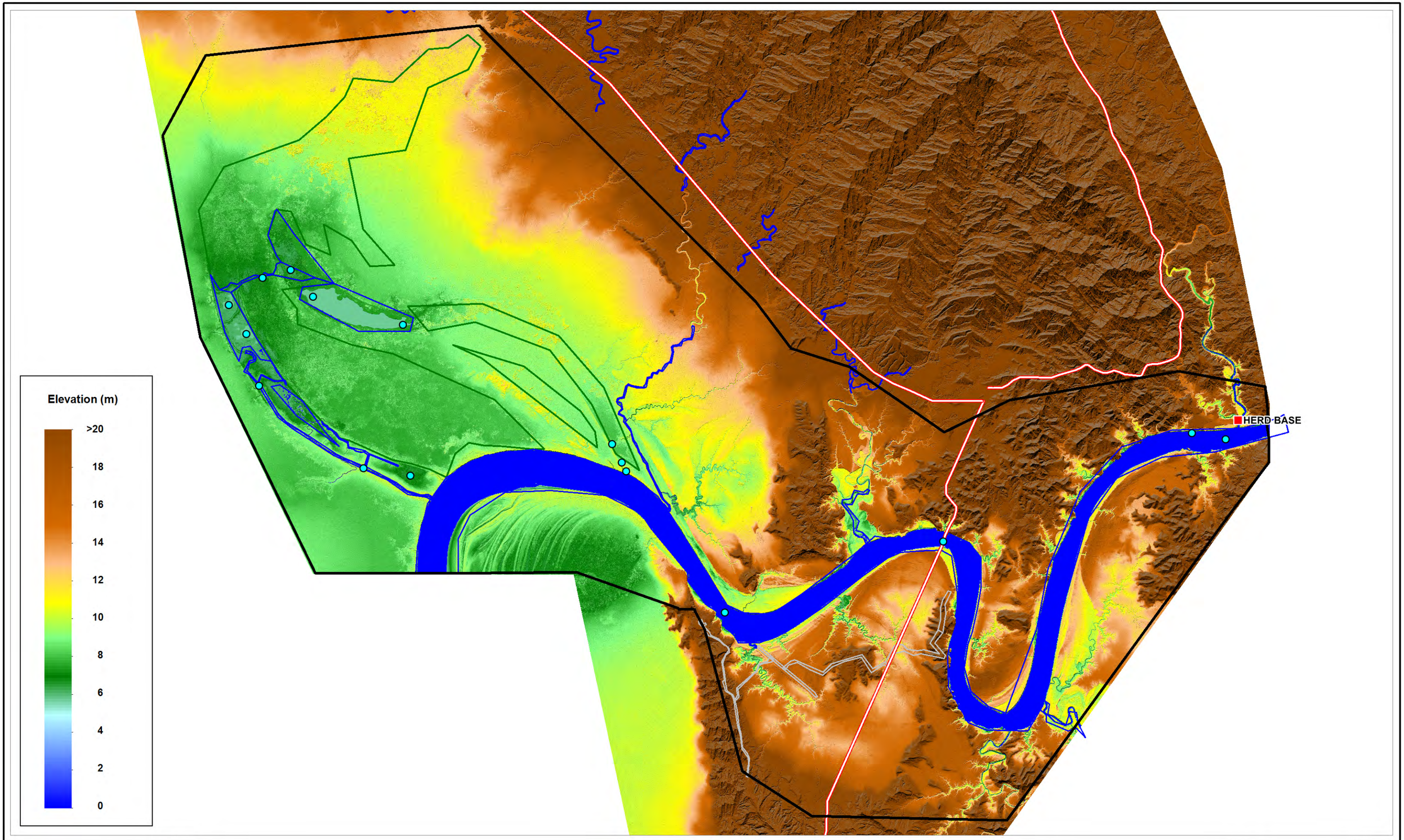
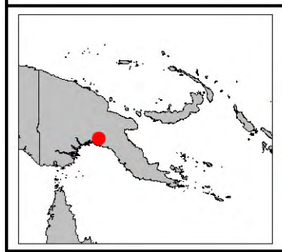


Figure 4-7 Comparison of the Elevation data between LiDAR and SRTM

The upstream inflow boundaries have been set as source-area (SA) inflows within the channel upstream of the potential trunkline and onshore export pipeline corridor waterway crossings. Some of the hydraulic models require multiple inflows. This is partly due to the combining of some crossings into a single model. For some of the hydraulic models it is due to a proportional breakup of the flows, due to insufficient breakup of the original sub-catchments as a result of the coarseness of original SRTM data. In some models, such as S1, infrastructure is expected to cross numerous tributaries which have no inflows applied. Inflow boundaries were not applied to these minor tributaries as they were not being assessed in this study as they were outside of the scope of the study (assessment of 20 sub-catchments) While the entire catchment has been considered in estimating flows at the crossing, consideration of the individual contribution of some smaller tributaries to these flows was not necessary as their flow would have been included within the main channel flow.

Recording points and lines have been included in the models at areas of interest, particularly at potential waterway crossing locations. Recording points have also been included in the model for additional areas of interest in the S10 model including Herd Base and the PRL-15 oxbow wetlands, as shown in Figure 4-8.





LEGEND

- TUFLOW Model Extent
- Water
- Medium Vegetation
- Roads
- Recording Location
- Trunkline Infrastructure Options
- Herd Base

Title:

Model S10 extent and recording locations

Figure: **4-8**

Rev: **A**

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Approx. Scale

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4.3 Rainfall-Runoff and Sediment Load Modeling

In order to describe baseline conditions, and for use in future impact assessments for the Project, a hydrological model capable of simulating a continuous longer-term historical period was constructed. This rainfall-runoff catchment model, described in Section 5.3, was used to estimate the flow (runoff) volume and load of total suspended sediment (TSS) for the Purari River catchment.

By simulating rainfall and runoff across the catchment for existing land use and climatic conditions as a baseline, the potential impacts of the Project can be assessed by comparing the changes to flow regimes, flow volumes, and TSS concentration/loads (see Section 5.3).

4.3.1 Model Development

4.3.1.1 The Source Modeling Framework

For this study, the eWater Source Modeling Framework (herein referred to as Source Catchments) (http://www.ewater.com.au/products/ewater-source/) was used to simulate the rainfall-runoff processes occurring in the study catchment.

Source Catchments is an application that can be used for both catchment and river modeling. Source provides a flexible structure that allows users to control the model complexity appropriate for the objective of the study and within constraints imposed available data and knowledge. Users can construct models by selecting and linking component models from a range of available options (Delgado *et al*., 2012).

Source Catchments is designed to:

- Support the construction and operation of catchment and river models. Water resource systems can be analyzed for periods that range from days to years; and
- Allow users to construct and interrogate water and contaminant transport models to assess the impact of future change, on parameters of interest.

Source Catchments integrates an array of models, data and knowledge used to simulate how climate and catchment variables (rainfall, evaporation, land use, vegetation) affect runoff, sediment transport and contaminants. Outputs can be used to offer scenarios and options for making improvements in a catchment and/or as input to other models.

4.3.1.2 Model Setup

The Source Catchments model is based on the following elements:

- **Sub-catchments**: The sub-catchment is the basic spatial unit, divided into hydrological response units (or functional units) based on a common response or behavior such as land use. Within each functional unit, three models can be assigned: a rainfall-runoff model, a constituent generation model and a filter model;
- **Nodes**: Nodes represent sub-catchment outlets, stream confluences or other places of interest such as stream gauges or dam walls. Nodes are connected by links, forming a representation of the stream network; and

- **Links**: Links represent the river reaches. Within each link, a selection of models can be applied to route or delay the movement of water along the link; or modify the contaminant loads due to processes occurring within the links, such as the decay of a particular constituent over time.

The Source Catchments (hydrological) model was configured to estimate the daily flow volume and TSS load from major sub-catchments of the existing Purari River catchment using the model configuration (nodes and links) shown on Figure 4-9.



Figure 4-9 Model Configuration for the Purari River Catchment

Catchment Delineation and Model Extents

A Digital Elevation Model (DEM) was generated using Shuttle Radar Topography Mission (SRTM) data with a spatial resolution of 90 m by 90 m. The SRTM data were supplemented with 1 m LiDAR data of the Purari River to enhance the definition of the water courses in the vicinity of PRL-15. The combined topographical datasets were used to delineate the catchment draining to the receiving environment using the CatchmentSIM terrain analysis software package. A total of 43 sub-catchments were delineated as shown on Figure 4-10, with a combined area of approximately 35,000 km^2.

Functional Units

Sub-catchments are divided into areas with a common hydrologic response or behavior called functional units (FUs), based on various combinations of land use or cover (e.g. bushland, rural, urban), management, position in landscape (flat, hill slope, and ridge) and/or hazard. FUs are used to reflect the different hydrologic responses in the area of interest (Delgado *et al*., 2012).

FUs in the Purari River catchment were classified according to clearance of native vegetation and the fraction of impervious surfaces expected within. This was undertaken using satellite imagery, broadly classifying the FUs into two categories – inland southern fold mountains and highland valleys. Correspondingly, the mid reaches of the catchment were mostly comprised of the eroded steep inland southern fold mountains with areas of clearing, and the more stable upper reaches of the catchment were generally defined by highland valley areas covered in dense vegetation, such as grassland.

The categories of land use include:

(1) **Inland southern fold mountains** – Includes areas of eroded steep escarpments conducive to landslides and high rates of sediment transport; and

(2) **Highland valleys** – Includes areas of heavy vegetation cover in the more geologically stable upper reaches of the catchment, mostly comprised of grassland.

The spatial distribution of the FUs were mapped using GIS and used as an input to the Source Catchment model. The proportional area of each FU within the sub-catchments were automatically assigned by the model using a gridded dataset.



Title:

Sub-Catchment Delineation

Figure: 4-10

Rev: A

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Approx. Scale

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Rainfall-runoff Model

The SIMHYD rainfall-runoff model was used to model runoff for all surface types defined in the model. SIMHYD is a conceptual rainfall-runoff model, which is itself a simplified version of the daily conceptual rainfall-runoff model, HYDROLOG that was developed in 1972. The model simplifies the rainfall-runoff processes and requires input of the following variables to perform the hydrological assessment:

- Rainfall;
- Potential evapotranspiration (PET); and
- Catchment parameters (area, pervious fraction, rainfall threshold, infiltration rates, field capacity, soil storage depths and groundwater parameters).

SIMHYD has been widely used in Australia and was applied for generating runoff for the Murray Darling Basin Sustainable Yields study in 2006-2008 (Delgado *et al*., 2012). SIMHYD model parameters are typically derived from calibration of the SIMHYD rainfall-runoff model to streamflow records if available for a study area. Details of the approach to model calibration used for this study are provided in Section 4.3.2.

Meteorological Data

The SIMHYD rainfall-runoff model estimates daily streamflow from daily rainfall and areal potential evapotranspiration data (APET). Generally, continuous records of climatic data are used as an input to the rainfall-runoff model. However, the available datasets for the Purari River catchment proved to be exceedingly limited with datasets exhibiting discontinuous data, missing and incomplete records, and spatially isolated gauging locations. These factors provided limitations for modelled data outputs and the predictions made for hydrologically dependent elements, namely sediment transport. Consequentially, rainfall was sourced using the joint NASA and Japan Aerospace Exploration Agency (JAXA) Tropical Rainfall Measuring Mission (TRMM) satellite dataset (see https://pmm.nasa.gov/TRMM/mission-overview). TRMM tropical and sub-tropical rainfall data is collected every 3 hours using 5 different microwave sensing instruments that are combined to form the dataset, and extends from 1997 to present (now operated as the Global Precipitation Mission [GPM]).

For the purpose of this assessment, an aggregated daily product of the TRMM rainfall data was used, spanning March 2000 to December 2016, across a spatial resolution of 0.25 degrees by 0.25 degrees (28 km by 28 km). These data provide spatially and temporally varying estimates of rainfall for the study region and as such, has been used for scenario modeling purposes (see Figure 4-11 for examples). For the purpose of this assessment, daily temperature data were sourced from the National Oceanic & Atmospheric Administration's Earth System Research Laboratory (NOAA ESRL) operated by the U.S. Department of Commerce (see https://www.esrl.noaa.gov/). The temperature was available as gridded 2.5 degree by 2.5 degree (280 km by 280 km) datasets using the NCEP Reanalysis dataset (1948-present) for air temperature, collected 4 times daily. Due to the size of the global grids used in the collection of NOAA ESRL data, two points (point A and point B) were chosen for analysis.

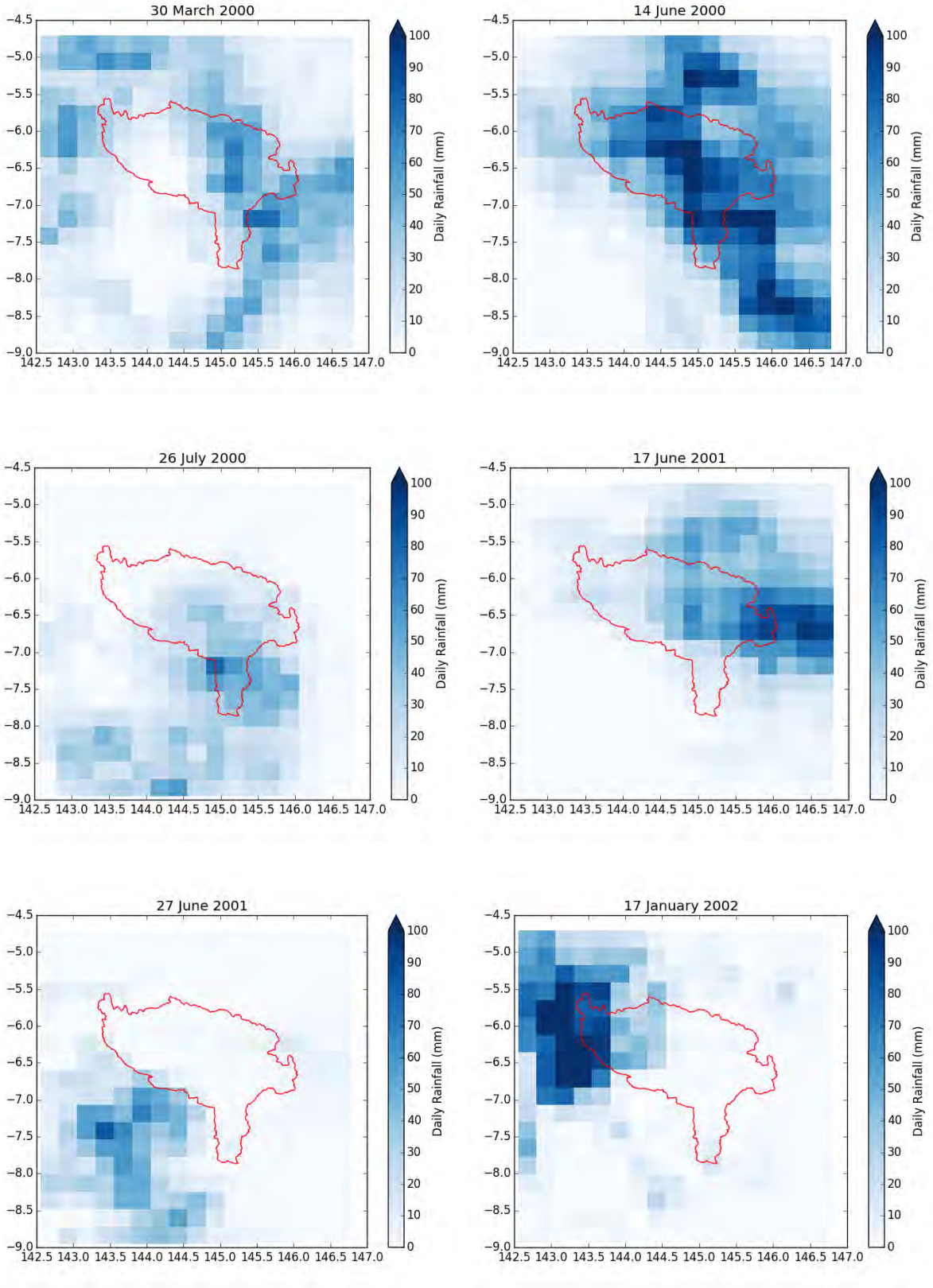


Figure 4-11 Example TRMM Rainfall Data

In the absence of an existing potential evapotranspiration (PET) dataset for the study area, PET was calculated using the Thornthwaite equation (1948) where:

$$PET = 16 + \left(\frac{L}{12}\right) + \left(\frac{N}{30}\right) + \left(\frac{10T_a}{I}\right)^a$$

- T_a is the average daily temperature of the month being calculated
- N is the number of days in the month being calculated
- L is the average day length in hours of the month being calculated
- $a = (6.75\ x\ 10^{-7})I^3 - (7.71\ x\ 10^{-5})I^2 + (1.792\ x\ 10^{-2})I + 0.49239$
- I is the heat index based on the 12 monthly mean temperatures (T_{ai}), where

$$I = \sum_{i=1}^{12} \left(\frac{T_{ai}}{5}\right)^{1.514}$$

The PET between January 1948 and December 2014 (inclusive) calculated from the ESRL NOAA data was 1379 mm at Point A and 1629 mm at Point B. To derive rainfall inputs for the Source model, the TRMM daily rainfall data were imported to Source to calculate average rainfall depth for each sub-catchment of the model. Example meteorological data used by the catchment model is shown in Figure 4-12. Figure 4-13 demonstrates the obvious seasonal variation associated with PET whereby PET is typically higher during the summer months, and lower during the cooler winter months. Also shown is the more contemporary trend of increasing PET from 2013 onwards.

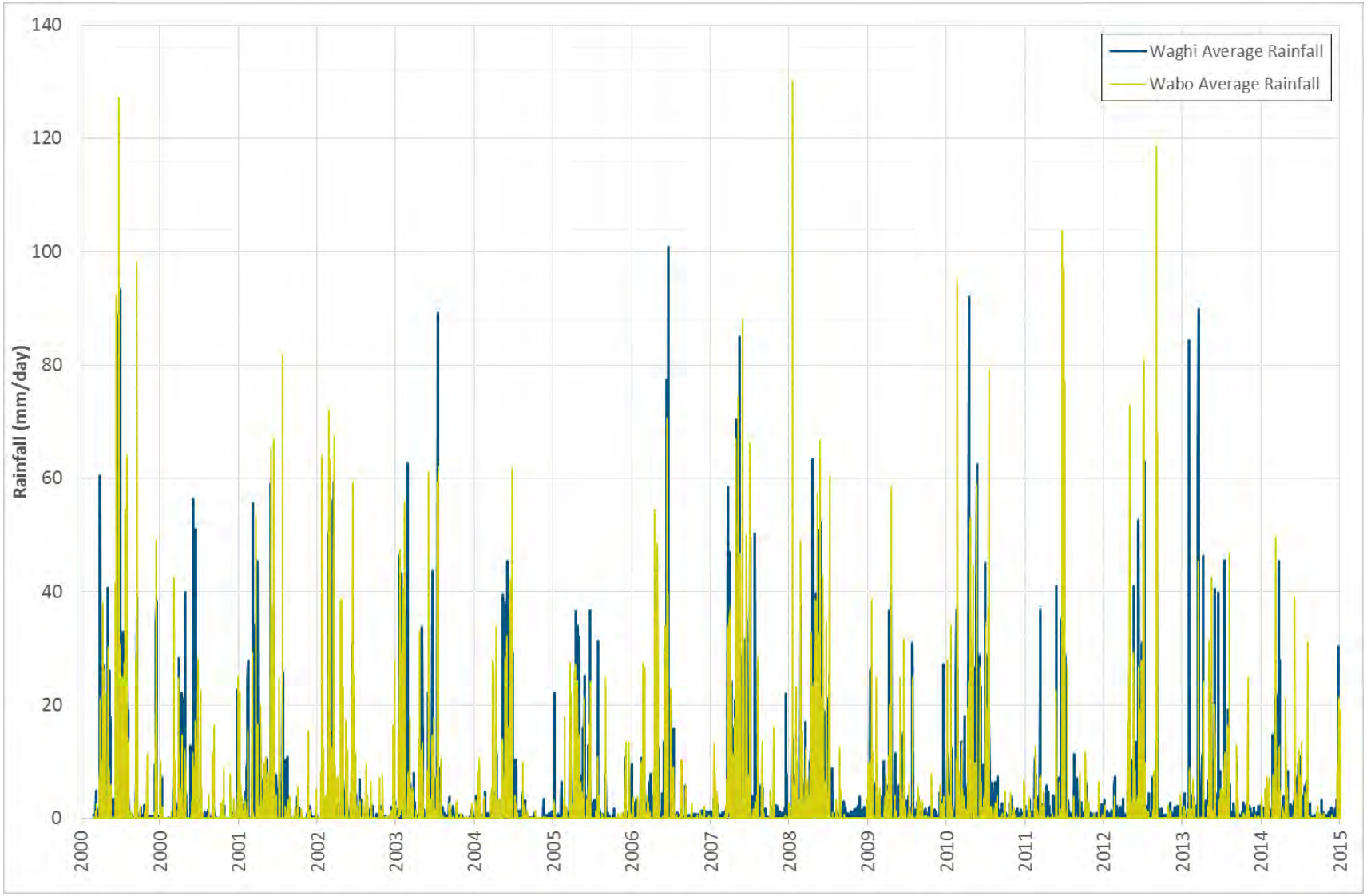


Figure 4-12 Time series of Catchment Average Rainfall

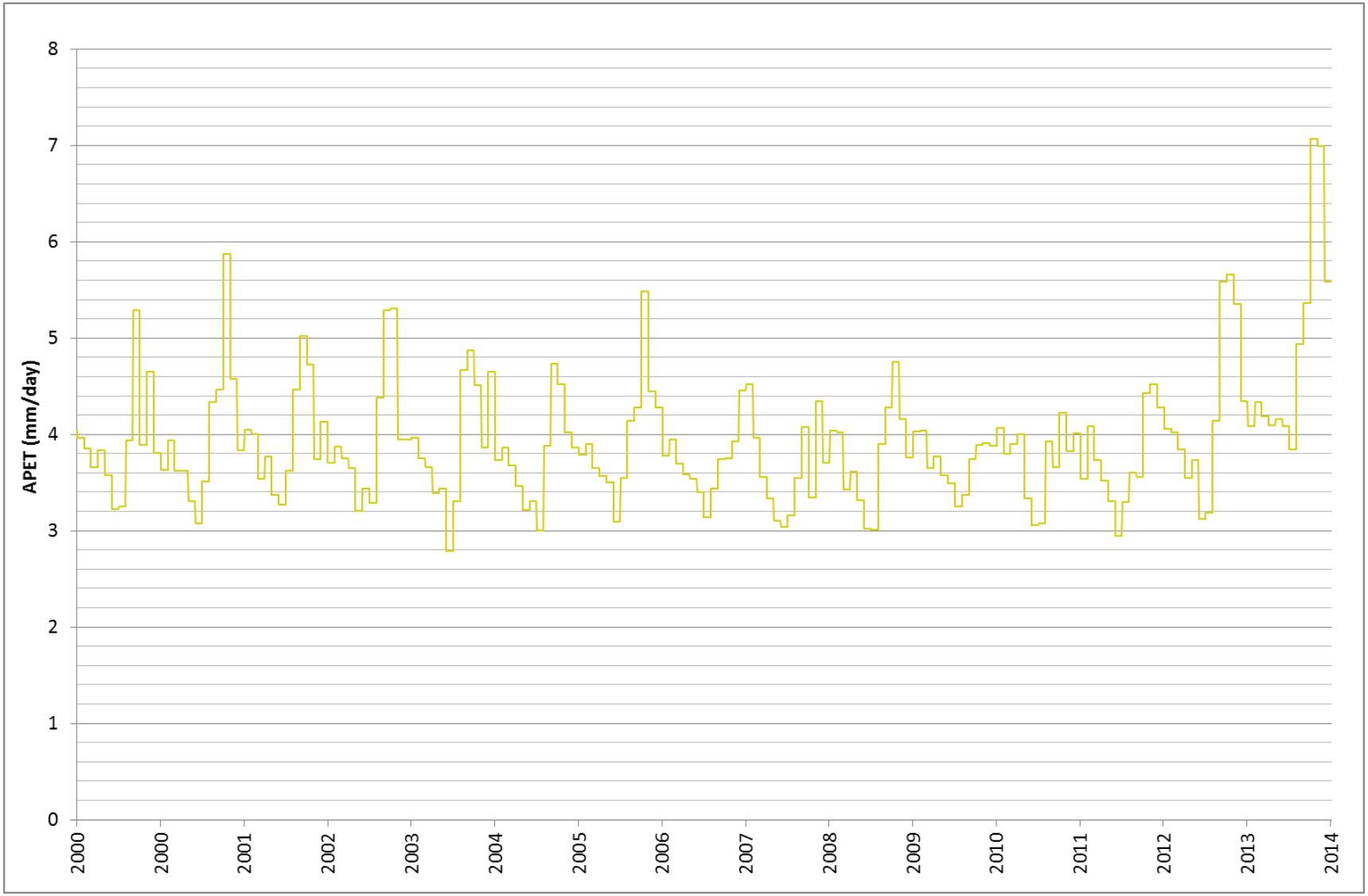


Figure 4-13 Time series of PET

Constituent Generation Model

In July 2016, a number of grab samples were collected from the Purari River and its tributaries, where both turbidity and TSS were measured. The relationship between these parameters is shown in Figure 4-14, which shows that a value of 1.16 is a suitable conversion factor between turbidity to TSS concentration. This value generally ranges between 1 and 2 depending on location of the receiving environment / waterway and its upstream catchment.

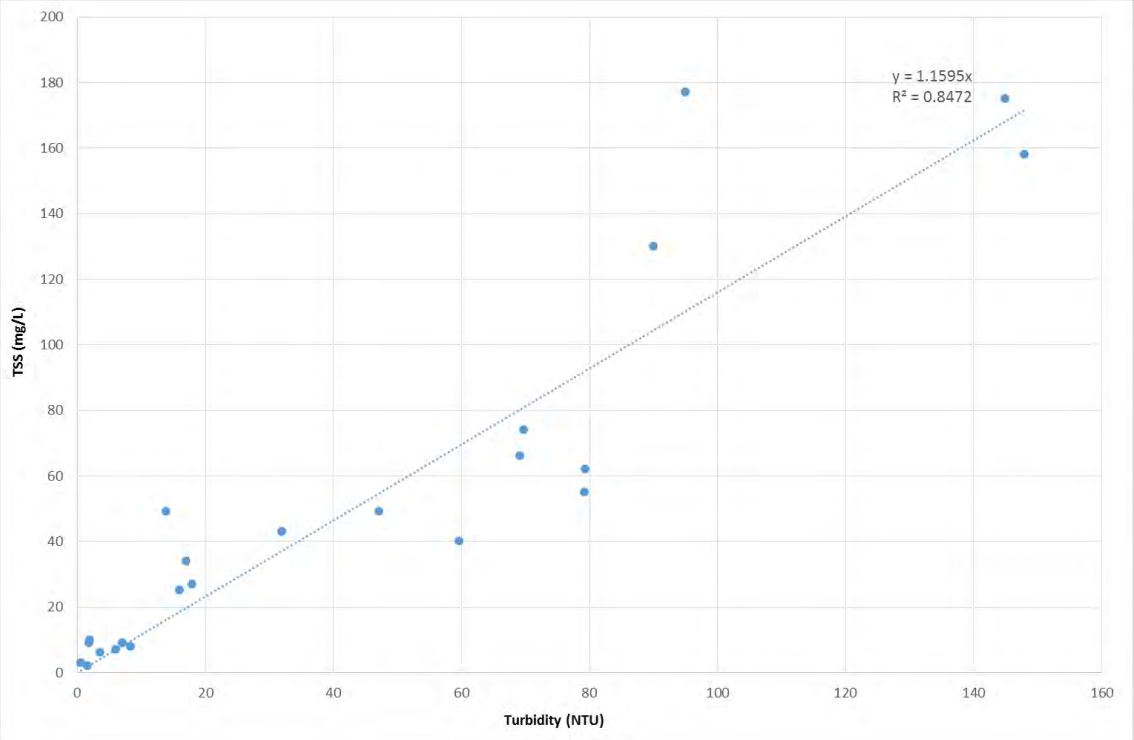


Figure 4-14 Relationship between Turbidity and TSS

Continuous measurements of turbidity collected over a 10-day period in February 2017 at 6 minute intervals are shown on Figure 4-15. This graph demonstrates a high baseflow TSS concentration of approximately 200 mg/L, with peak concentrations up to 1,400 mg/L in response to rainfall events on the 17 and 18 February when high flows were experienced on the Purari River.

TSS concentrations were modelled using the power function model available within the Source modeling platform. This model generates an empirical relationship between catchment derived total TSS concentrations and catchment flows. This method has successfully been used in other large-scale catchment modeling projects in PNG such as the Golpu Project ESIA – Catchment and Receiving Water Quality Monitoring (BMT WBM, 2015). The power function assumptions were validated against field data collected for the Papua LNG Project. The power function parameters used are summarized in Table 4-13.

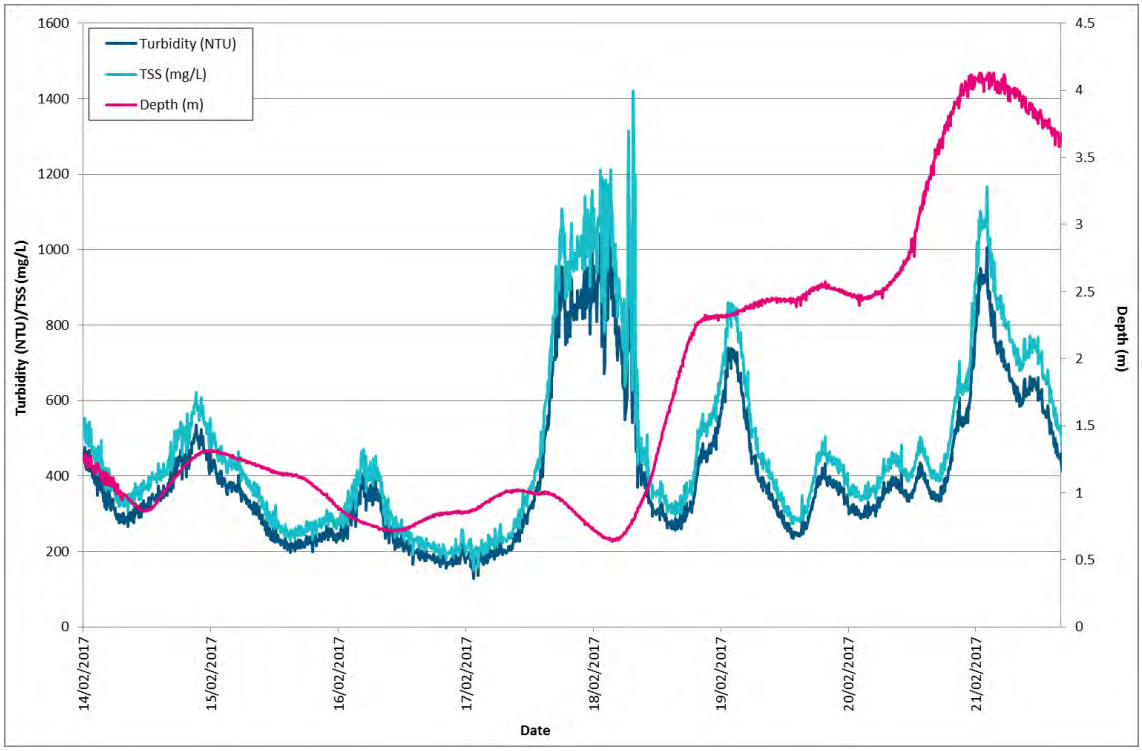


Figure 4-15 Relationship between TSS, Turbidity and Depth

Table 4-13 Adopted Constituent Model Parameters

Parameter	a (the slope of the curve)	b (curvature of the curve whereby B > 1 is concave and B < 1 is convex)	c (mg/L) (the concentration of the constituent at low flow)	Maximum Concentration (mg/L) (maximum concentration of a sediment or solute)
Adopted Value	0.15	1.25	200	8000

Estimation of Daily Runoff Volume

Pickup and Chewings (1983) note that the mean annual runoff volume for the Purari Basin is approximately 2,617 mm and varies depending on the topography and the contribution from other local sub-catchments locations. Within sub-catchments close to the southern fold mountains, runoff depth ranges between 2,000 and 4,000 mm/year, whereas the more inland highlands exhibit runoff depths ranging from 1,000 to 2,000 mm/year. This is directly related to the rainfall received in the respective areas of the broader catchment.

4.3.2 Model Calibration

4.3.2.1 Calibration Approach

Calibration of the SIMHYD rainfall-runoff model was limited by the quality and availability of rainfall and streamflow data across the catchment. Due to the large catchment area, highly variable rainfall

and lack of adequate streamflow data, regional estimates of rainfall (i.e. the TRMM data adopted for scenario modeling) could not be adopted for model calibration purposes.

To calibrate the SIMHYD model, the Waghi River sub-catchment was modelled using CEPA gauged rainfall data for Chimbu and Asaro, with the overlapping period available for the CEPA gauged streamflow data at Waghi River. This was undertaken to obtain an estimate of catchment parameters for the SIMHYD model, (rather than using the default parameters) to provide an improved representation of the hydrology of the Purari River catchment.

Overlapping rainfall and streamflow gauge data for the Purari River catchment was limited to two datasets:

- Streamflow data on the Purari River at Wabo and rainfall at the Wabo rainfall gauge; and
- Streamflow data at the Waghi River station and rainfall at the Asaro rainfall gauge.

The contributing catchment area of the Purari River upstream of Wabo Creek junction is approximately 28,738 km^2, compared to the 4,757 km^2 area of the Waghi River catchment, and as such, cannot be calibrated against the streamflow or rainfall measured at one gauge site due to the spatial and temporal variability across the large catchment. Without calibration, and because of the lack of a comprehensive overlapping gauged dataset for streamflow and rainfall, the default SIMHYD parameters would need to be adopted. However, the default SIMHYD parameters are not suitable for simulating rainfall-runoff in the Purari River catchment as they do not accurately reflect the catchment conditions.

Preliminary calibration of the model was therefore undertaken for the Waghi River sub-catchment by applying rainfall from the Asaro rainfall gauge (station 705090) and comparing modelled flow estimates to the Waghi River stream flow gauge (station 704850). Several attempts to calibrate the SIMHYD model against streamflow at Waghi River were undertaken, however, due to poor data quality and short length of the record, only a modest calibration result could be obtained, however, this is considered to be an improvement upon adopting default SIMHYD parameters.

4.3.2.2 Flow Calibration Results

Flow gauging data provides the basis for estimating catchment parameters and the predictive performance of the catchment model. The following rainfall and stream gauging data was available for estimation of the rainfall-runoff parameters:

- **Stream Flow:** Station 704850 (Waghi River upstream of Nimai Creek junction); and
- **Rainfall:** Station 705090 (Asaro at Amaiyufa School).

Catchment parameters for the SIMHYD rainfall-runoff model were estimated for the Waghi River sub-catchment by calibrating the model against flow measurements recorded at gauging station 704850. The auto calibration tool available in Source was used to estimate catchment parameters for the SIMHYD model which are provided in Table 4-14.

Table 4-14 Adopted SIMHYD Rainfall-Runoff Parameters

Parameter		Bushland	Cleared
Impervious Area	Impervious Threshold (mm)	2.4	1.0
Pervious Area	Pervious Fraction	1.0	0.9
	Soil Moisture Storage Capacity (mm)	100	320
	Rainfall Interception Store Capacity (mm)	0.5	1.5
	Infiltration Coefficient	398	200
	Infiltration Shape	0.96	3.0
	Interflow Coefficient	0.22	0.10
	Recharge Coefficient	1.0	0.20
	Baseflow Coefficient	0.035	0.30

The above parameters provided a flow response comparable to the observed stream flow data as shown in Figure 4-16. The streamflow corresponding to default SIMHYD catchment parameters demonstrate a highly unreliable runoff response to the rainfall as shown by the exceedingly high peaks in the simulated streamflow data. During baseflow conditions, the default SIMHYD parameters result in zero flows and do not provide a true representation of the low flow conditions within the Waghi River. In contrast, the simulated streamflow obtained using the calibrated SIMHYD catchment parameters provide a streamflow response similar to the recorded streamflow gauge data. This is particularly evident during baseflow conditions and during rainfall events where the simulated rise and recession of streamflow follow a similar shape to the gauged data.

Key Findings of Model Calibration

The results of the model calibration were a reflection of the poor-quality data, extensive data gaps, temporal and spatially sparse data, and of the lack of historical documentation regarding catchment hydrology. As such, the calibration focused on simulating a catchment response similar to the gauged data along the Waghi River to provide at least an estimate of typical rainfall-runoff response for the study catchment. This approach was successful in deriving suitable catchment parameters for the Waghi catchment, which are applied to the broader Purari River Source model for scenario modeling purposes in the absence of any other information.

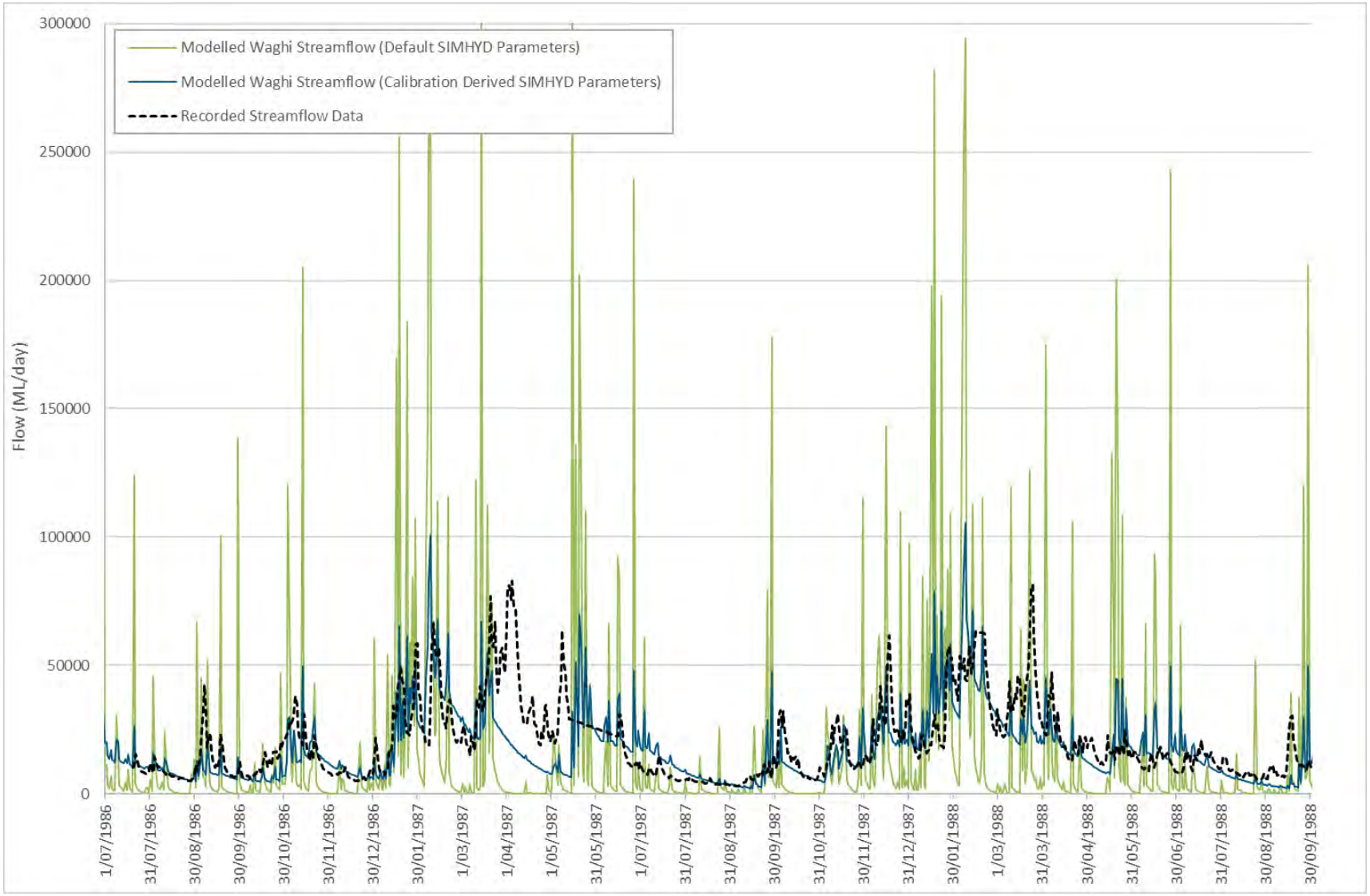


Figure 4-16 Time series of Daily Runoff Volume for the Waghi River Sub-catchment

5 Modeling Results for Baseline Characterization

This section presents the results for modeling that is relevant to baseline characterization. This includes the results of IFDs and hydrographs produced by hydrological modeling, the flood levels and velocities for hydraulic modeling, and the sediment transport estimates for the rainfall-runoff modeling.

5.1 Hydrological Modeling

The results for the hydrological modeling have been discussed in Section 4.1.4. The URBS hydrologic model was validated to the FFA and RFF for the 10 year, 50 year and 100 year. In order to achieve this validation with the peak flows, the rainfall continuing losses had to be reduced to 0.5 mm/hr. The peak flows produced by the URBS model tended to be less than the FFA, but higher than the RFF as shown in Table 4-11.

A critical storm duration analysis was undertaken for each of the catchments that were used as inflows to the hydraulic models. The critical storm duration is a measure of the time floodwaters (runoff) takes to travel from the top of the drainage catchment to a specific location along the waterway. The critical storm durations were as follows;

- S10 (Purari River/Herd Base) - 72 hours (Figure 5-1);
- S20 - 36 hours; and
- All other models - 6 hours.

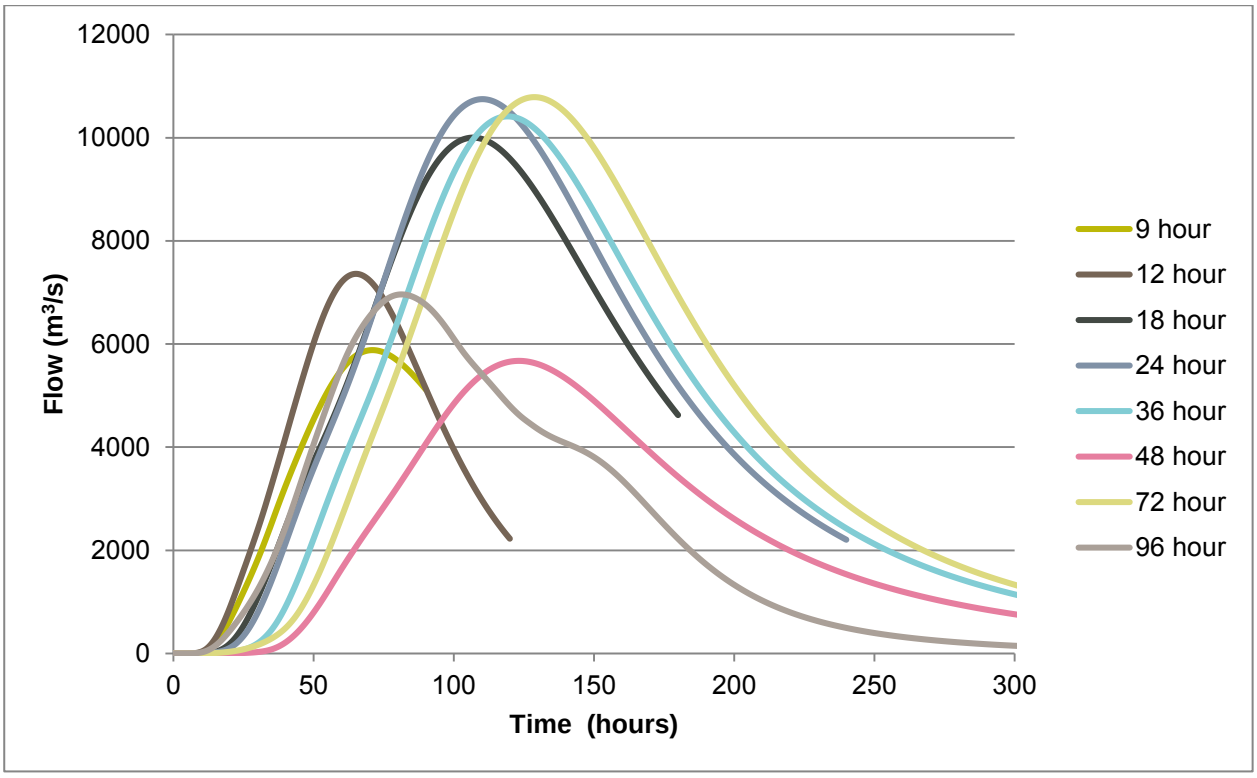


Figure 5-1 URBS Hydrographs for the S10 (Purari River/Herd Base) Model Inflow

5.2 Hydraulic Modeling

Each of the TUFLOW models were simulated for the 10 year, 50 year and 100 year ARI events. Model result plots for peak flood level and velocity for each event modelled are provided in Appendix D for potential trunkline and onshore export pipeline corridor waterway crossings. The model results also show flood extents in the minor tributaries for which no inflow was included into the model. This is where the modelled flow has backed up into these areas. The model results in these locations have not been validated and should not be used for any design calculations or specifications.

The hydraulic modeling results showed that there were generally two types of waterways associated with the potential trunkline and onshore export pipeline corridor waterway crossings: well-defined or poorly defined channels. The hydraulic models S1 to S10 and S18 (nine models) represent areas that have well-defined channels, where the majority of the flow was contained within the channel. The remainder of the hydraulic models (seven models) represent areas that exhibit poorly defined channels. The locations that had better defined channels and flood extents tended to be located at higher elevations, whilst the poorly defined channel crossings were at lower elevations.

The hydraulic modeling results showed very similar flood extents for the 10 year, 50 year and 100 year for the models that represented well-defined channels as floodwater was mostly contained within the channels. One exception to this was noted in the S8 model, which predicted that flow escaped (overtopped) the channel downstream of the potential crossing location for the 100 year ARI event. However, the smaller events in the S8 model were predicted to be contained within the channel for the full extent of the model.

The hydraulic models that represented the less well-defined channels predicted greater flood extents for the larger ARI flood events. Model results indicated that the flow escaped the main channels in smaller events. That is, the channel capacity was smaller and not able to carry the larger flows. Model results showed that the larger ARI events (larger flow) tended to increase the number of flow paths that were engaged within the model extent.

The S10 model results showed that some of the flow from the 50 year and 100 year ARI events, can potentially bypass the bend downstream of Herd Base, while the 10 year ARI flow was contained within the channel. However, it is important to note that these results may change when channel bathymetry is included to the model.

As expected, the hydraulic modeling results showed that the models representing areas of steeper terrain resulted in higher modelled velocities. The highest modelled velocity (7.8 m/s) was in the S8 model, near recording point 12.

5.3 Rainfall-Runoff and Sediment Transport Modeling

The following section presents an analysis of catchment modeling results for existing (baseline) catchment conditions, with regard to runoff volume, flow regime and sediment concentration/load.

Source Catchments is used for modeling river systems and typically focuses on the balance and volume of water within these systems. As such, Source commonly outputs data in a volume per unit time, such as ML/day for large models (1000 ML/day is equal to 11.6 m^3/s).

The analysis of catchment modeling results for the existing Purari River catchment is presented in Section 5.3.1 and includes the following:

- Statistical summary of runoff volume and TSS loads;
- Estimation of baseflow contribution to streamflow (i.e. the base flow index (BFI) and mean daily baseflow volume); and
- Characterization of existing streamflow conditions (flow volume and TSS load) based on the above.

For the purpose of this assessment, reporting locations were used to demonstrate the existing conditions upstream, downstream and within the area of PRL-15. The reporting locations include:

(1) Location 1 – representative of Purari River flow and loads upstream of PRL-15 at sub-catchment (SC) 24

(2) Location 2 – representative of the local flows and loads at Hou Creek Base located along Hou Creek in sub-catchment 34

(3) Location 3 – representative of the local flows and loads along Boa Creek in sub-catchment 36

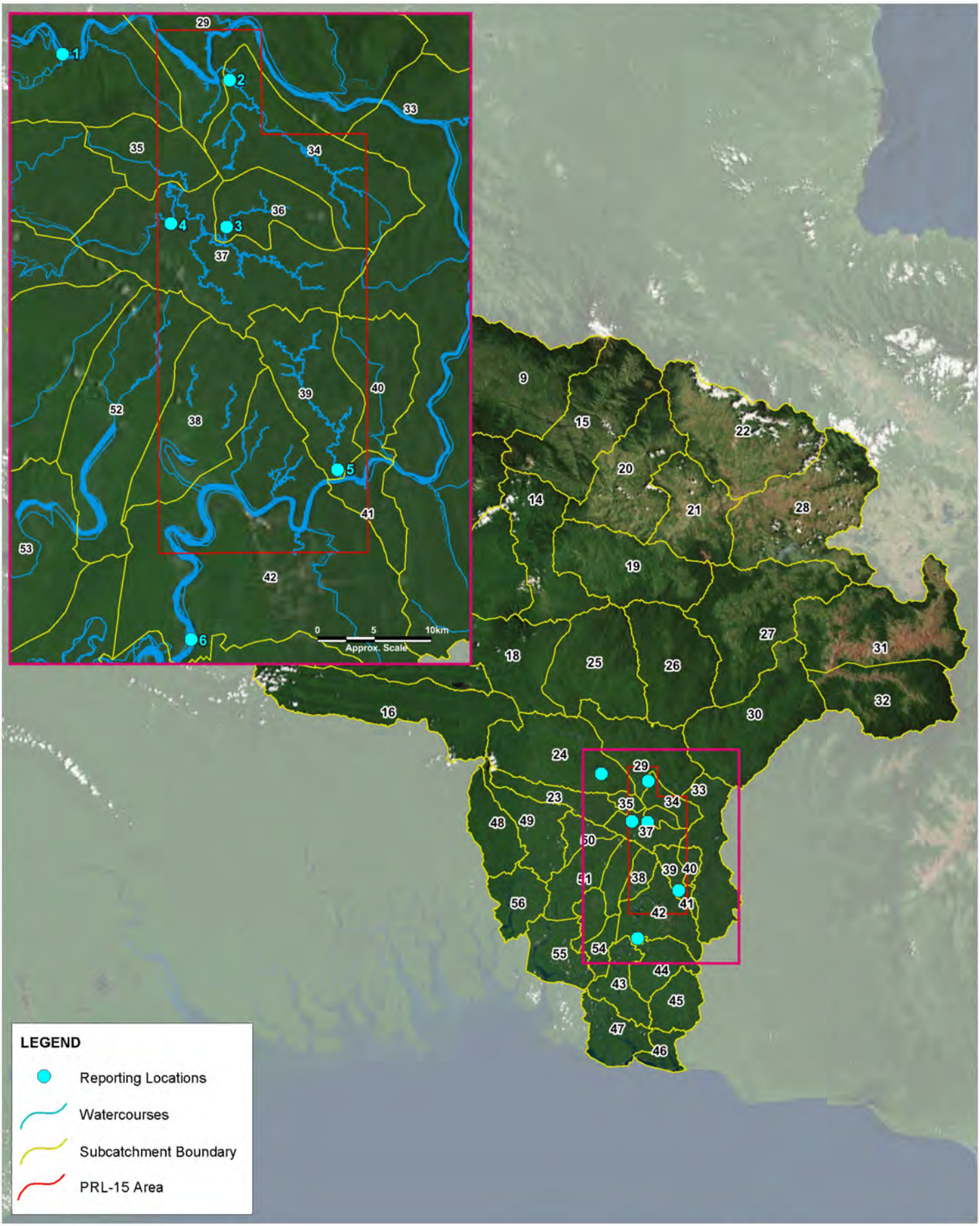
(4) Location 4 – representative of the local flows and loads of the Mena River before its confluence with the Era River in sub-catchment 37

(5) Location 5 – representative of the local flows and loads of Kuku Creek at Herd Base in sub-catchment 39

(6) Location 6 – representative of Purari River flow and loads downstream of PRL-15 at sub-catchment 42.

The reporting locations used are shown in Figure 5-2.

NOTE: The sub-catchments shown in Figure 5-2 differ from those used for hydrological modeling (see Figure 4-1) as some sub-catchments have been merged and others further subdivided for the purposes of reporting representative locations.



Title:

Reporting Locations

Figure: 5-2

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 25 50km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : K:\B21414_Elk-Antelope_Project\GIS\MI\Workspaces\Figures\DRG003_Reporting_Locations.WOR

5.3.1 Existing Conditions

5.3.1.1 Streamflow

Characterization of Streamflow

Streamflow along the Purari River and its tributaries in the vicinity of the PRL-15 site demonstrates obvious seasonality as shown in Figure 5-3. Mean monthly streamflow totals across the simulated duration show the months of May, June and July as having the greatest monthly average streamflow for all three reporting locations. The period May to July falls within the south-easterly trade wind season extending from May to October each year, concurrent with the findings of Pickup and Chewings (1983) for the greatest amount of rainfall experienced by the inland southern fold mountains. November and December had the lowest mean monthly streamflow across the modelled duration, likely to be due to drier conditions within the inland southern fold mountains during this period.

Baseflow Contribution to Streamflow

The baseflow contribution to streamflow is used to assess low-flow characteristics of rivers using the mean daily streamflow. The base flow index (BFI) of a system represents the ratio of long-term baseflow to the total streamflow (Gustard *et al*. 1992). The BFI for each location can be summarized as below:

- Location 1 (SC 24) had a BFI of 0.37 with a mean daily baseflow of 6,478 ML/day (75.0 m^3/s). The annual BFI across the modelled duration ranged from 0.32 to 0.55.
- Location 2 (SC 34) had a BFI of 0.33 with a mean daily baseflow of 34 ML/day (0.4 m^3/s). The annual BFI across the modelled duration ranged from 0.21 to 0.54.
- Location 5 (SC 39) had a BFI of 0.34 with a mean daily baseflow of 20 ML/day (0.2 m^3/s). The annual BFI across the modelled duration ranged from 0.22 to 0.54.
- Location 6 (SC 42) had a BFI of 0.38 with a mean daily baseflow of 8,470 ML/day (98.0 m^3/s). The annual BFI across the modelled duration ranged from 0.34 to 0.57.
- The BFI at each reporting location was generally higher between May to October each year, corresponding to the elevated stream flows during the south-easterly trade wind season from elevated runoff in the catchment.

The similar BFI across all locations indicates that for most of the modelled duration, around one third of the total streamflow is attributed to baseflow along the Purari River and its tributaries, with some months experiencing around half of the total streamflow from baseflow. Additionally, based on modeling results it is apparent that Location 2 has a significantly lower mean daily baseflow when compared to Location 1 and 6. This implies that potential impacts within the boundaries of PRL-15 site would have a negligible impact on the downstream streamflow and BFI at the catchment scale.

Flow Volume

The flow volume of the Purari River catchment upstream of the PRL-15 site is represented by Location 1 (SC24) in Figure 5-3 below. The following observations can be made based on the results of this modeling:

- Daily flows at Location 1 (SC24), representing the Purari River catchment upstream of PRL-15, generate peak runoff volumes in excess of 250,000 ML during high flow events with a mean daily flow of 17,500 ML/day. These volumes are associated with the large catchment area (30,700 km^2) upstream of this location
- Location 2 (SC34) generates in excess of 2,000 ML/day during periods of high rainfall and has a mean flow of 100 ML/day
- Location 3 (SC36) generates in excess of 1,000 ML/day during periods of high rainfall and has a mean flow of 40 ML/day
- Location 4 (SC37) generates in excess of 2,000 ML/day during periods of high rainfall and has a mean flow of 133 ML/day. This represents an increased mean flow of 1,000 ML/day between locations 3 and 4.
- Location 5 (SC39) generates in excess of 1,500 ML/day during periods of high rainfall and has a mean flow of 58 ML/day.
- Location 6 (SC42), representing the Purari River catchment downstream of PRL-15, has peak flows in excess of 250,000 ML/day with a mean flow of approximately 22,400 ML/day. This represents an increased mean flow of 5,000 ML/day between locations 1 and 6.
- The sub-catchments within PRL-15 (i.e.; locations 2 and 5) represent approximately 3.3% of the total contribution to mean daily flow volumes between locations 1 and 6, indicating a negligible contribution by PRL-15 to the Purari River catchment.

A summary of the modelled streamflow results is shown in Table 5-1.

Table 5-1 Existing Streamflow at the Selected Reporting Locations (Sub-catchments)

Reporting Location	Catchment Area (km^2)	Mean Daily Flow (ML/day)	Mean Annual Flow (ML/year)
1	30,700	17,500	6,325,430
2	136	102	36,791
3	53	40	14,389
4	177	133	48,076
5	89	58	20,929
6	32,920	22,400	8,106,615

Flow Duration

Flow duration is a key indicator of streamflow characteristics and was calculated as a percentage of time equaled or exceeded for a range of flow conditions (i.e.; high and low flows) across the reference locations, as shown in Figure 5-4.

The flow duration for the reference locations is summarised below:

- At Location 1, 95% of the time flows are greater than 150 ML/day (5 percentile flow), 50% of the time flows are greater than 6,500 ML/day (median flow), 10% of the time flows are greater than 45,000 ML/day (90 percentile flow), and 5% of the time flows are close to 80,000 ML/day (95 percentile flow).
- At Location 2, 95% of the time flows are less than 1 ML/day (5 percentile flow), 50% of the time flows are greater than 25 ML/day (median flow), 10% of the time flows are greater than 275 ML/day (90 percentile flow) and 5% of the time flows are greater than 450 ML/day (95 percentile flow).
- At Location 5, 95% of the time flows are less than greater than 1 ML/day (5 percentile flow), 50% of the time flows are greater than 15 ML/day (median flow), 10% of the time flows are greater than 150 ML/day (90 percentile flow) and 5% of the time flows are greater than 250 ML/day (95 percentile flow).
- At Location 6, 95% of the time flows are greater than 250 ML/day (5 percentile flow), 50% of the time flows are greater than 10,000 ML/day (median flow), 10% of the time flows are greater than 60,000 ML/day (90 percentile flow), and 5% of the time flows are close to 100,000 ML/day (95 percentile flow).

The modelled data shows that the low flow (5 percentile flow) at Location 2 and Location 5 (~1 ML/day) is approximately 0.4% of the low flow at Location 1 and 0.7% of the low flow at Location 6. High flows (90 percentile flow) at Location 2 and 5 were greater than 150 ML/day, however, this still represents approximately 0.3% the high flows modelled at Location 1 and 6. The large difference between the 90 and 95 percentile flows at all locations suggest the entire system is highly responsive to runoff, particularly as it becomes saturated during prolonged rainfall events.

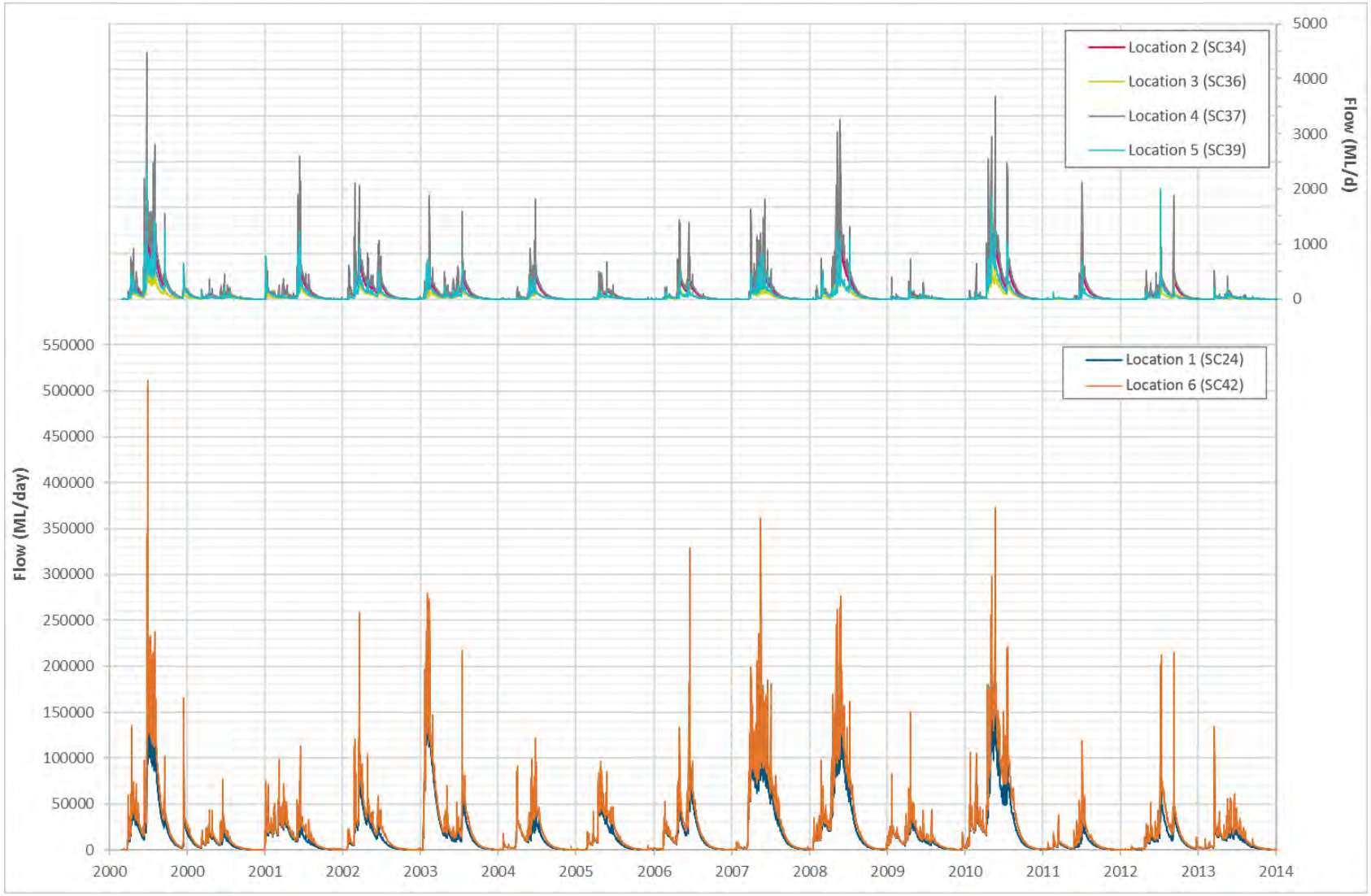
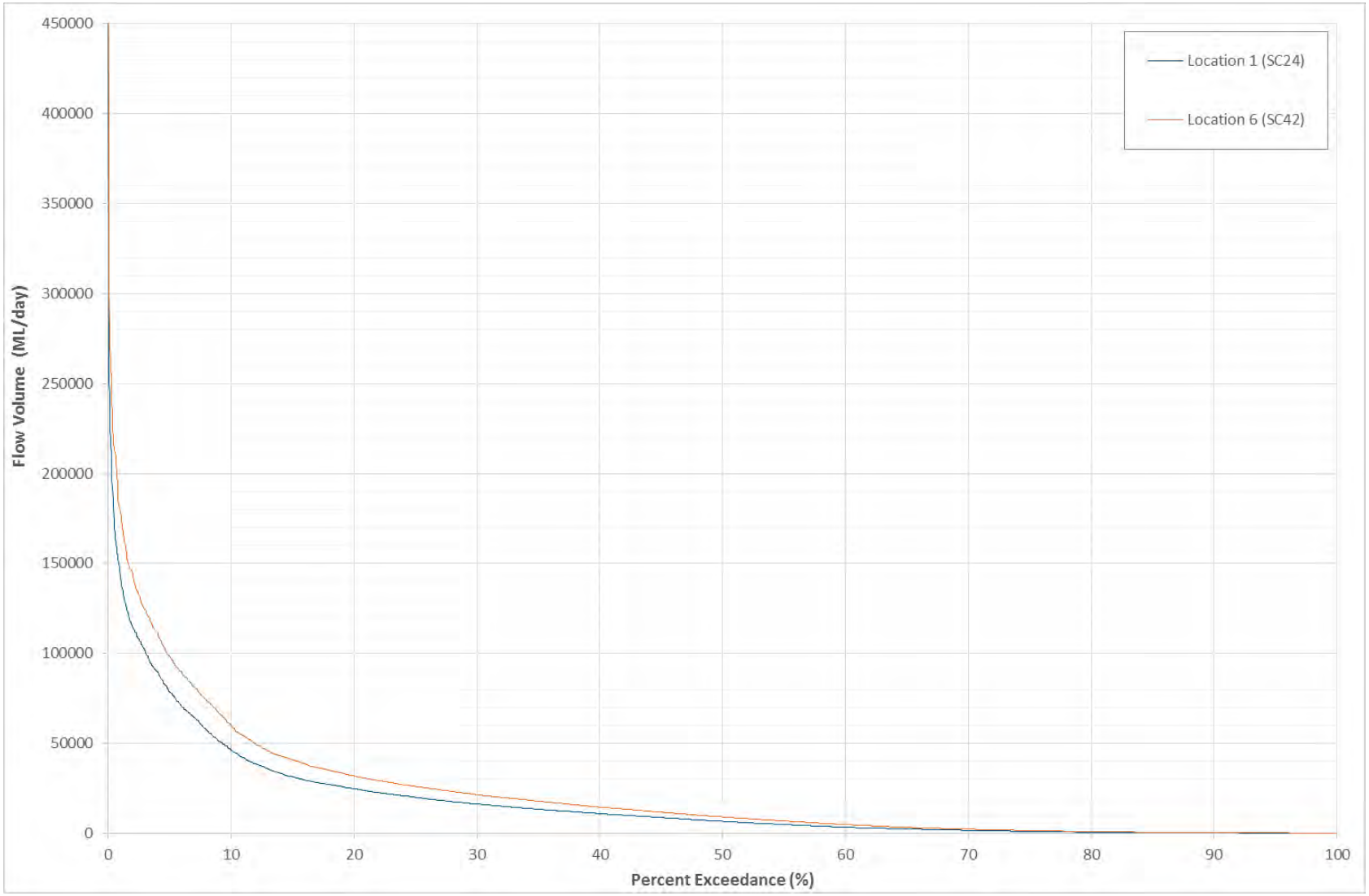


Figure 5-3 Downstream Flow Volume at Selected Reporting Locations


Location 1 (SC24)
Location 6 (SC42)
Flow Volume (ML/day)
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
0
10
20
30
40
50
60
70
80
90
100
Percent Exceedance (%)

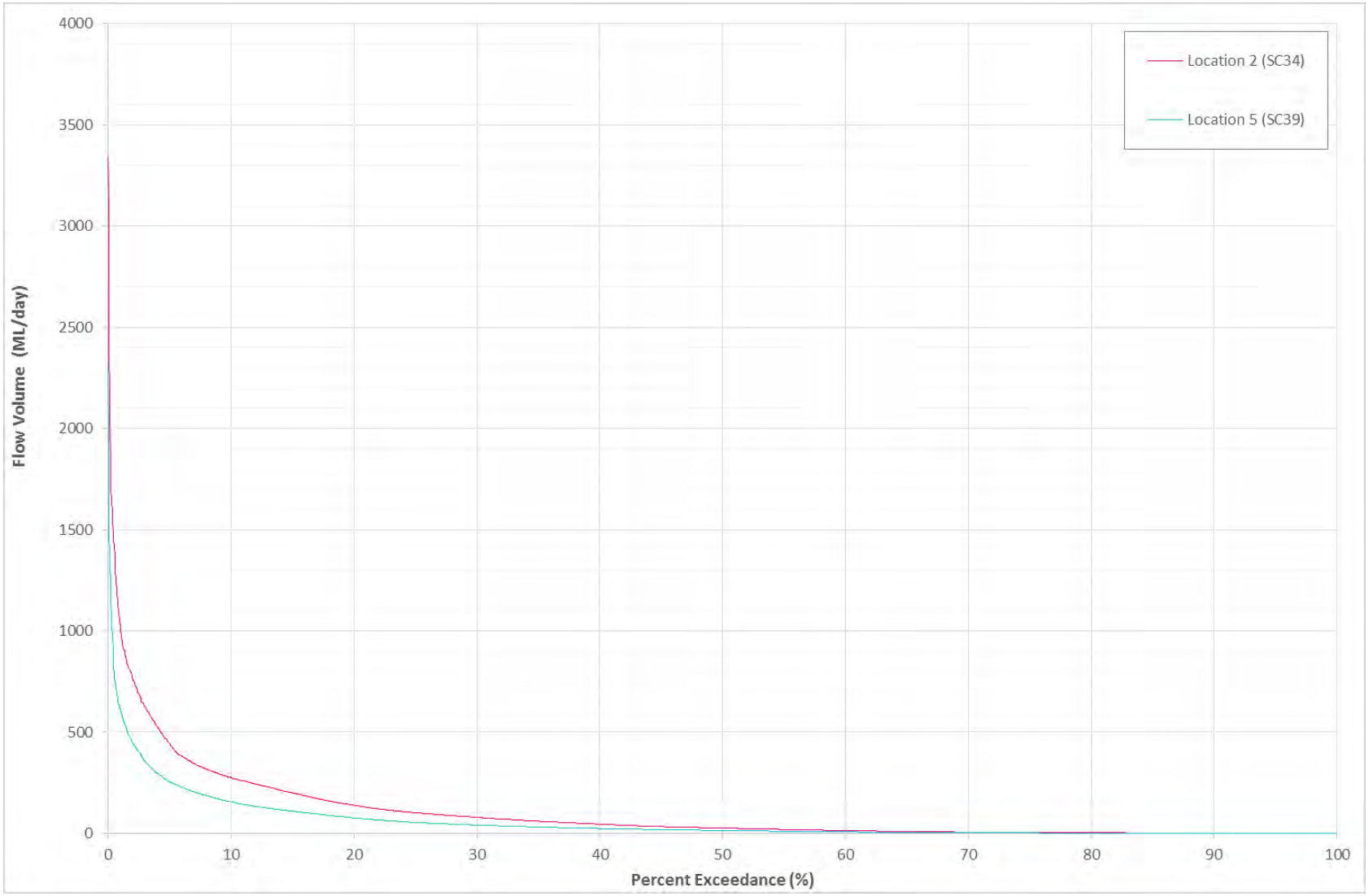


Figure 5-4 Flow Duration Curves at Selected Reporting Locations

5.3.1.2 TSS

The TSS load within the Purari River catchment was modelled to describe existing conditions, upon which relative impacts arising from Project development can be estimated. Pickup and Chewings (1978) estimated, based on limited data, that at Wabo (upstream of Location 1), the Purari River catchment transports (on average) approximately 57 million tons of sediment per year, with the Aure River catchment to the east transporting approximately 48 million tons of sediment per year.

The modelled TSS load for the reporting locations is shown in Figure 5-5, which shows seasonality of TSS loads. Peak TSS loads are transported between May and August in response to the increased rainfall (and runoff volume) during the south-easterly trade wind season responsible for transporting sediment through the catchment. The mean annual TSS at the reporting locations is considered to be typical of the amount of sediment expected to be transported from the upper catchment.

A summary of the TSS loads from each reporting location is given in Table 5-2.

Table 5-2 Existing TSS Loads at the Selected Reporting Locations (Sub-catchments)

Reporting Location	Mean Daily TSS Loads (t/day)	Mean Annual TSS Loads (t/year)
1	64,702	23,390,045
2	67	24,332
3	14	4931
4	112	40,506
5	27	9771
6	80,948	29,263,023

At Location 1, the mean annual TSS loads were approximately 23 million t/year, and at Location 6 were approximately 29 million t/year. These reported values are within the estimations made by Pickup and Chewings (1987) (noting that Source only estimates suspended loads and not bed loads), with Location 6 receiving sediment from both the Purari and Aure River catchments. The reporting locations within PRL-15 (i.e.; locations 2 to 5) had considerably lower mean annual TSS loads, between 0.1% (Location 2) and 0.2% (Location 4) of the TSS load at Location 1. Furthermore, even lower TSS loads were modelled at Location 3 and Location 5, which represented approximately less than 1% of the mean annual TSS loads at Location 1. This is reflective of the smaller contributing catchment areas within the boundaries of PRL-15 site.

These results indicate that the dominant contribution of TSS loads in the Purari River downstream of Hathor Gorge come from the Aure River catchment rather than PRL-15 catchments. Total volumes discharged from the PRL-15 sub-catchment are negligible, representing less than 1% of the 6 million t/year difference in TSS loads between Locations 1 (upstream of PRL-15) and 6 (downstream of PRL-15).



Figure 5-5 TSS Load at Selected Reporting Locations

6 Statement of Model Use

This section provides an overview of the recommended use of modeling results, noting the limitations discussed in further detail in Section 7.

6.1 Hydrologic Modeling

The hydrologic model that has been developed for this assessment is fit for purpose. However, it has only been validated to a single gauge location and only to peak flow estimates using design rainfall. It would benefit from calibration with numerous gauges throughout the catchment.

6.2 Hydraulic Modeling

The majority of the hydraulic models that have been developed for this assessment are fit for purpose and the results can be used to assess the study area, in particular the pipeline waterway crossings. The main exception to this is the S10 Herd Base Purari River model. As described in Section 4.2.1, this model does not include bathymetry in the river and a significant assumption has been required in relation to the shape and depth of the Purari River channel.

6.3 Rainfall-Runoff and Sediment Loads Modeling

The rainfall-runoff model that has been developed for this assessment is fit for purpose. However, only partial calibration of rainfall-runoff parameters could be achieved due to limitations with the available meteorological data and streamflow gauge records.

It is recommended that the current model be used to assess relative changes between the existing and proposed development conditions using results at monthly intervals to address limitations of model calibration and input data which affect the accuracy of daily runoff and sediment load/concentrations.

7 Limitations

7.1 Hydrology and Hydraulics

The following limitations in the study approach are noted:

- There are a number of minor waterway crossings that have not been assessed as part of this study.
- Due to data paucity the models for hydrology and hydraulic assessments are uncalibrated and unvalidated. In addition, insufficient data was available to undertake a detailed rainfall frequency analysis. Instead, the methodology provided in the PNG Flood Estimation Manual was utilized.
- Bathymetric data (including cross-sections) was unavailable at the time of undertaking hydraulic modeling activities. As a result, a 'generic' channel profile for the Purari River has been adopted, based on previous experience with waterways in Papua New Guinea.
- Whilst current industry practice techniques have been applied, the work relies on the use of theoretical runoff events. Future runoff events may differ, resulting in different flooding. Catchment gauge data is considered unreliable and therefore there remains some uncertainty in the model accuracy. Whilst an FFA has been undertaken for the Purari River upstream of Wabo Creek, which is upstream of the site, no historic flood data within the model boundaries is available to verify flow characteristics at the site.
- Numerous minor waterways crossing have not been assessed as part of this study, although some of the model result will show flood extents and velocities at these locations. These results are due to backflow from the main channel for which a flow has been applied.
- In preparing this report, BMT WBM relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by ERIAS Group and/or available in the public domain. Except as otherwise stated in the report, BMT WBM has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.
- BMT WBM derived the data in this report from information available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. BMT WBM has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.
- This report has been prepared on behalf of, and for the exclusive use of ERIAS Group and TEP PNG and is subject to, and issued in accordance with, the provisions of the contract between BMT WBM and ERIAS. BMT WBM accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

- Furthermore, this analysis is based on a desktop theoretical analysis of potential flooding, with reliance on numerical flow models using theoretical design flood flows, and on empirical equations. This assessment represents a preliminary assessment of the flooding characteristics of the site to support the ESBS. If the proposed development proceeds, further flooding investigations are recommended. This assessment of flooding should not be used to inform design decisions relating to infrastructure required for the project.

7.2 Rainfall-Runoff and Sediment Loads

The following limitations in the study approach are noted:

- Due to data scarcity (both temporally and spatially) and the lack of long-term data availability, the catchment model is uncalibrated and un-validated. Additionally, insufficient data were available to undertake a detailed rainfall frequency analysis.
- The predictive capacity of the catchment model is reduced if model calibration and validation is undertaken using measurements that do not fully capture or represent the true variability of water quality within the study catchment.
- No modeling of prevailing geomorphological processes within study area waterways (e.g. stream movement) has been undertaken or is proposed as part of the Project EIS/ESHIA.
- No receiving water quality model (RWQM) has been developed for the purposes of characterizing existing water quality, particularly in relation to TSS. This was not considered necessary due to the naturally high volumes of sediment within the Purari River and the relatively small area expected to be subject to land-use conversion as a result of the Project. That is, additional sediment loads from the Project development are expected to be small and therefore can be assessed using a semi-quantitative approach in the first instance.

The catchment model was rationalized in order to describe climate, hydrology, and constituent generation characteristics as best as possible, however, with regards to climate data the following assumptions are highlighted:

- Rainfall in the two broad catchment regions, namely the highlands and the southern fold mountains, is assumed to be the same due to the lack of spatially variable data. The spatial variability of rainfall across these regions is high and cannot be adequately represented by one or two rainfall gauge sites; and
- Potential evapotranspiration that describes the combined process of water surface evaporation, soil moisture evaporation, and plant transpiration is assumed to be uniform across the entire Purari River catchment.

With regards to hydrologic and constituent generation:

- Constituent (TSS) generation is identical across the entire catchment.
- Variations are expected in the model predictions for catchment derived flows and constituent loads if the hydrology and constituent generation characteristics vary across corresponding catchments, although insufficient data are available to adequately address this.

These limitations are not anticipated to impact on the ability to characterize the baseline hydrology and sediment transport conditions for the preparation of an EIS/ESHIA. However, the results of this assessment are indicative only and not intended to inform detailed engineering design and/or investigations.

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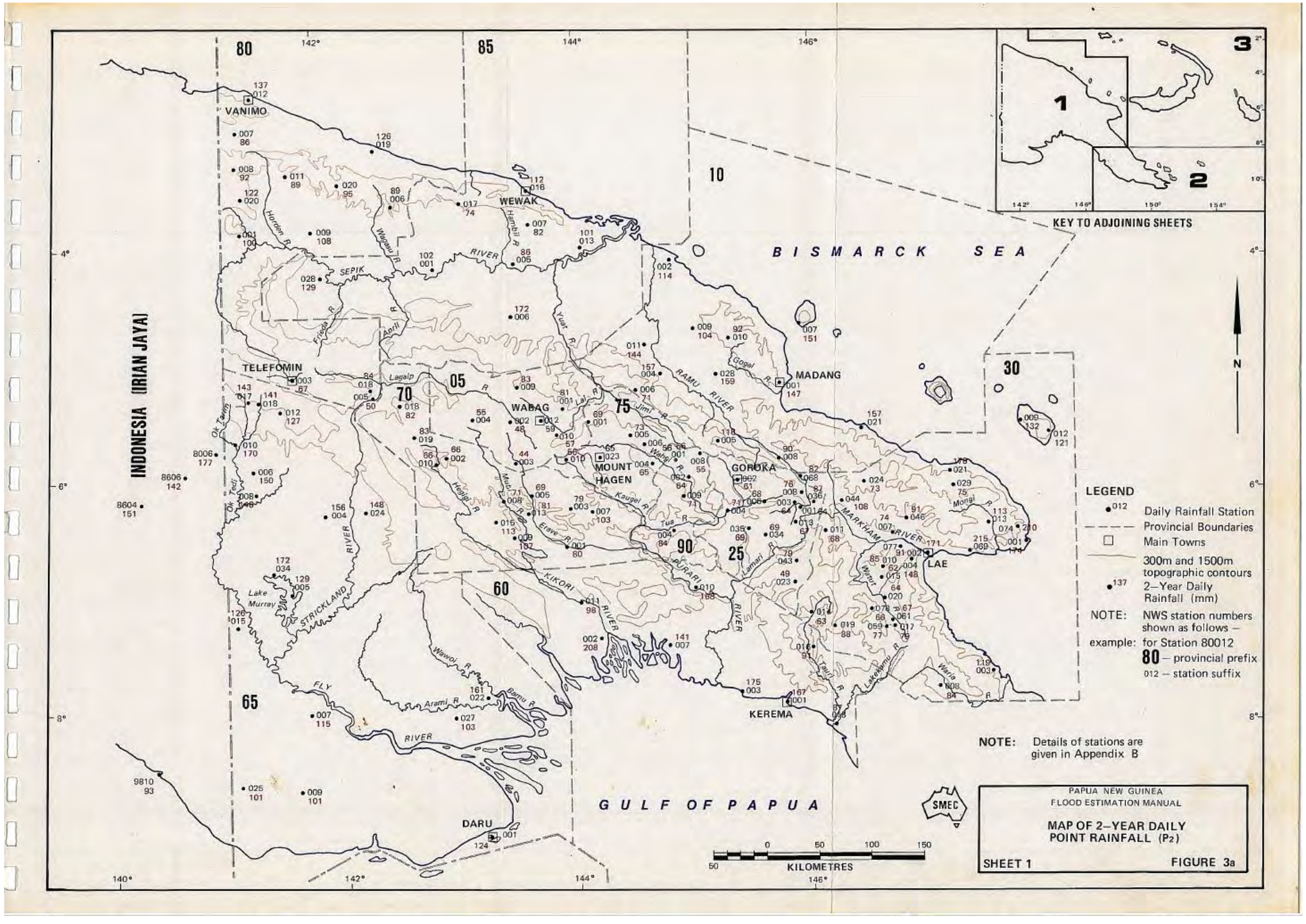
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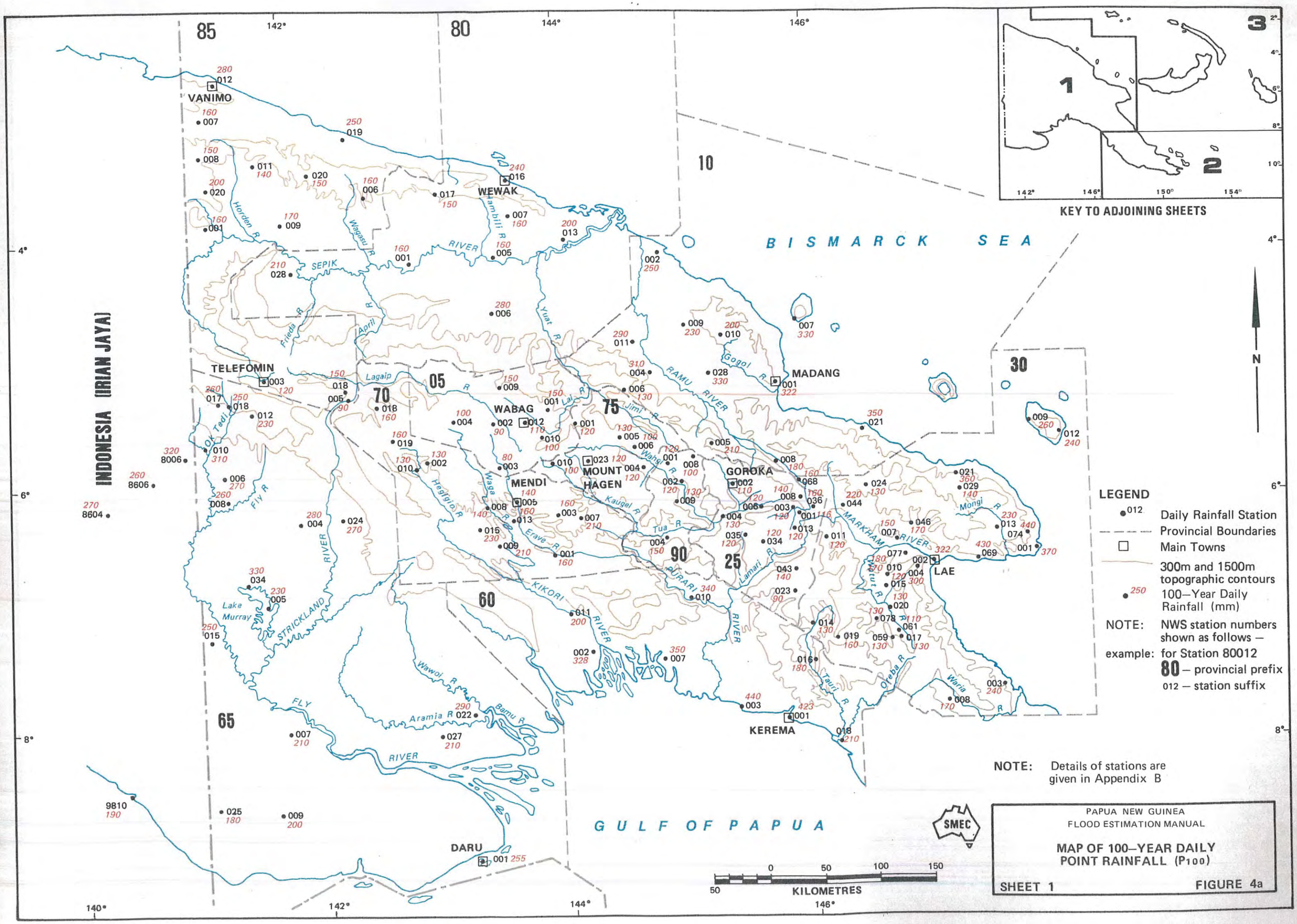
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Appendix A PNG Flood Estimation Manual Figure 3a and 4a


INDONESIA (IRIAN JAYA)
BISMARCK SEA
GULF OF PAPUA
KEY TO ADJOINING SHEETS
VANIMO
WEWAK
TELEFOMIN
WABAG
MOUNT HAGEN
GOROKA
MADANG
LAE
KEREMA
DARU
Lake Murray
SEPIK RIVER
RAMU RIVER
STRICKLAND RIVER
FLY RIVER
MARKHAM RIVER
KIKORI RIVER
Horden R.
Wagawu R.
Hanbil R.
Yuat R.
Gogol R.
Jimi R.
Waghi R.
Kaugel R.
Tua R.
Lamari R.
Purari R.
Erave R.
Mubi R.
Heiagi R.
Ok Tedi
Ok Tanina
Lagaip R.
April R.
Frieda R.
Wawoi R.
Aramia R.
Bamu R.
Lakekamu R.
Tauri R.
Mong R.
Waria R.
Werur R.
80
85
10
90
25
60
65
70
05
75
30
LEGEND
012 Daily Rainfall Station
Provincial Boundaries
Main Towns
300m and 1500m topographic contours
137 2–Year Daily Rainfall (mm)
NOTE: NWS station numbers shown as follows –
example: for Station 80012
80 – provincial prefix
012 – station suffix
NOTE: Details of stations are given in Appendix B
PAPUA NEW GUINEA
FLOOD ESTIMATION MANUAL
MAP OF 2–YEAR DAILY POINT RAINFALL (P2)
SHEET 1
FIGURE 3a
SMEC
KILOMETRES
N


INDONESIA (IRIAN JAYA)
PAPUA NEW GUINEA
BISMARCK SEA
GULF OF PAPUA
VANIMO
WEWAK
TELEFOMIN
MADANG
WABAG
MENDI
MOUNT HAGEN
GOROKA
LAE
KEREMA
DARU
85
80
10
70
05
75
30
60
90
25
65
142°
144°
146°
4°
6°
8°
Horden R
Wagasu R
Yambili R
RIVER
SEPIK
Frieda R
April R
Yuat R
Gogol R
RAMU RIVER
Lagaip R
Lai R
Jimi R
Waghi R
Waga R
Hagiolo R
Kaugel R
Tua R
Erave R
KIKORI RIVER
PURARI RIVER
Lamari R
Markham River
Mongi R
Waria R
Tauri R
Oreba R
OK Tedi
FLY R
FLY RIVER
STRICKLAND RIVER
Lake Murray
Wawoi R
Aramia R
Bamu R
KEY TO ADJOINING SHEETS
1
2
3
LEGEND
Daily Rainfall Station
Provincial Boundaries
Main Towns
300m and 1500m topographic contours
100–Year Daily Rainfall (mm)
NOTE: NWS station numbers shown as follows –
example: for Station 80012
80 – provincial prefix
012 – station suffix
NOTE: Details of stations are given in Appendix B
SMEC
0 50 100 150
50 KILOMETRES
PAPUA NEW GUINEA
FLOOD ESTIMATION MANUAL
MAP OF 100–YEAR DAILY POINT RAINFALL (P100)
SHEET 1
FIGURE 4a

Appendix B Daily Rainfall Point Totals

Sub-catchment ID	P2	P5	P10	P20	P25	P50	P100
1	162.5	224.2	265.3	304.1	315.5	352.1	390.9
2	163.5	209.8	240.7	269.9	278.5	305.9	335.1
3	166.3	213.3	244.6	274.2	282.9	310.7	340.3
4	165.9	213.8	245.7	275.9	284.8	313.1	343.3
5	163.0	210.2	241.7	271.4	280.2	308.2	337.9
6	166.8	215.6	248.2	278.9	287.9	316.9	347.6
7	167.3	216.4	249.2	280.1	289.2	318.3	349.2
8	166.9	217.0	250.3	281.8	291.1	320.8	352.3
9	166.6	217.4	251.3	283.3	292.8	322.9	354.9
10	166.4	217.9	252.2	284.6	294.2	324.7	357.1
11	166.3	218.5	253.4	286.3	295.9	326.9	359.8
12	166.4	219.5	254.9	288.4	298.2	329.7	363.1
13	166.2	219.6	255.2	288.8	298.7	330.3	363.9
14	160.7	213.1	248.0	281.0	290.7	321.7	354.7
15	168.3	230.3	271.6	310.6	322.1	358.8	397.8
16	168.7	231.4	273.2	312.7	324.3	361.5	401.0
17	168.9	232.0	274.1	313.9	325.5	363.0	402.7
18	169.3	233.3	276.0	316.2	328.1	366.0	406.3
19	169.6	234.1	277.1	317.7	329.7	367.9	408.5
20	170.0	235.5	279.1	320.4	332.5	371.3	412.5
21	171.1	238.4	283.3	325.7	338.1	378.0	420.4
22	171.8	240.2	285.9	329.0	341.6	382.2	425.3
23	172.2	241.3	287.4	330.9	343.7	384.7	428.2
24	172.7	242.4	288.8	332.7	345.6	386.8	430.7
25	172.9	242.9	289.6	333.7	346.6	388.1	432.2
26	172.0	240.6	286.4	329.6	342.3	383.0	426.2
27	174.4	245.6	293.0	337.8	351.0	393.2	438.0
28	67.6	84.9	96.4	107.2	110.4	120.6	131.5
29	76.6	95.5	108.1	120.1	123.6	134.8	146.7
30	54.3	67.6	76.5	84.9	87.4	95.3	103.7
31	77.9	97.6	110.7	123.1	126.7	138.4	150.8
32	76.6	94.6	106.6	118.0	121.3	132.0	143.3
33	92.2	116.8	133.2	148.7	153.3	167.9	183.4
34	70.7	89.5	102.0	113.8	117.3	128.4	140.2
35	56.4	70.1	79.3	87.9	90.4	98.6	107.2
36	68.1	83.2	93.3	102.9	105.7	114.7	124.2

Sub-catchment ID	P2	P5	P10	P20	P25	P50	P100
37	70.1	85.1	95.1	104.6	107.4	116.2	125.7
38	66.9	82.5	92.8	102.6	105.5	114.7	124.5
39	63.2	78.1	88.0	97.4	100.2	109.0	118.4
40	61.9	75.8	85.0	93.8	96.3	104.6	113.3
41	66.2	80.9	90.7	99.9	102.6	111.4	120.6
42	129.5	165.2	189.1	211.6	218.2	239.4	261.9
43	156.7	200.2	229.2	256.6	264.6	290.4	317.8
44	80.0	98.3	110.4	121.9	125.3	136.1	147.6
45	77.9	97.0	109.8	121.8	125.3	136.7	148.7
46	102.2	129.7	148.0	165.3	170.4	186.7	204.0
47	126.6	160.1	182.4	203.5	209.7	229.5	250.6
48	92.6	116.4	132.3	147.3	151.7	165.8	180.8
49	104.8	131.2	148.8	165.4	170.3	185.9	202.5
50	65.1	79.3	88.8	97.7	100.3	108.8	117.7
51	62.3	75.3	84.0	92.2	94.7	102.4	110.6
52	124.5	157.8	179.9	200.9	207.0	226.8	247.7
53	95.6	118.8	134.2	148.8	153.1	166.8	181.4
54	68.0	81.6	90.6	99.2	101.7	109.7	118.3
55	72.9	88.0	98.1	107.6	110.4	119.4	128.9
56	84.7	106.8	121.6	135.5	139.6	152.7	166.6
57	88.3	108.6	122.1	134.8	138.6	150.6	163.3
58	82.7	104.8	119.5	133.4	137.4	150.5	164.4
59	86.8	106.9	120.3	133.0	136.7	148.6	161.3
60	95.2	120.5	137.4	153.4	158.0	173.1	189.0
61	87.7	107.9	121.3	134.0	137.7	149.7	162.4
62	93.2	116.5	132.1	146.8	151.1	164.9	179.6
63	86.4	105.7	118.5	130.7	134.2	145.7	157.8
64	83.8	101.8	113.7	125.0	128.4	139.0	150.3
65	86.9	106.1	118.9	131.0	134.5	145.9	158.0
66	80.9	102.2	116.4	129.8	133.8	146.4	159.8
67	78.4	98.5	111.8	124.5	128.2	140.1	152.7
68	75.6	91.8	102.6	112.8	115.8	125.4	135.6
69	81.8	101.0	113.8	125.9	129.4	140.8	152.9
70	70.0	85.6	96.0	105.8	108.7	118.0	127.8
71	68.9	84.3	94.6	104.4	107.2	116.4	126.1
72	74.4	90.5	101.3	111.5	114.5	124.0	134.2
73	86.9	106.8	120.1	132.7	136.3	148.2	160.7
74	168.0	214.4	245.4	274.6	283.2	310.8	340.0

Sub-catchment ID	P2	P5	P10	P20	P25	P50	P100
75	160.0	207.3	238.8	268.5	277.3	305.3	335.0
76	145.0	193.6	226.0	256.6	265.6	294.4	325.0
77	150.0	205.4	242.3	277.1	287.4	320.2	355.0
78	141.0	200.1	239.6	276.8	287.7	322.8	360.0
79	156.7	200.2	229.2	256.6	264.6	290.4	317.8
80	46.0	56.5	63.6	70.2	72.1	78.4	85.0

Appendix C PNG Flood Estimation Manual Temporal Patterns

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TABLE 4.2 - DESIGN STORM TEMPORAL PATTERNS FOR DURATIONS OF UP TO 1 HOUR

	PERCENTAGE OF TOTAL STORM RAINFALL IN EACH TIME INCREMENT											
	10 MINUTES DURATION IN 2 Time Increments of 5 Minutes											
Time Increment Number	1	2										
Return Period ≤ 30 Years	57	43										
Return Period > 30 Years	54	46										
	15 MINUTES DURATION in 3 Time Increments of 5 Minutes											
Time Increment Number	1	2	3									
Return Period ≤ 30 Years	32	50	18									
Return Period > 30 Years	33	47	20									
	20 MINUTES DURATION in 4 Time Increments of 5 Minutes											
Time Increment Number	1	2	3	4								
Return Period ≤ 30 Years	19	43	30	8								
Return Period > 30 Years	20	40	30	10								
	25 MINUTES DURATION in 5 Time Increments of 5 Minutes											
Time Increment Number	1	2	3	4	5							
Return Period ≤ 30 Years	17	28	39	9	7							
Return Period > 30 Years	18	26	15	11	10							
	30 MINUTES DURATION in 6 Time Increments of 5 Minutes											
Time Increment Number	1	2	3	4	5	6						
Return Period ≤ 30 Years	16	25	33	9	11	6						
Return Period > 30 Years	16	24	30	10	12	8						
	45 MINUTES DURATION in 9 Time Increments of 5 Minutes											
Time Increment Number	1	2	3	4	5	6	7	8	9			
Return Period ≤ 30 Years	4.8	14.2	24.7	18.3	9.5	11.6	7.5	6.1	3.3			
Return Period > 30 Years	5.3	13.9	23.3	17.7	9.8	11.7	7.9	6.5	3.9			
	1 HOUR DURATION in 12 Time Increments of 5 Minutes											
Time Increment Number	1	2	3	4	5	6	7	8	9	10	11	12
Return Period ≤ 30 Years	3.9	7.0	16.8	12.0	23.2	10.1	8.9	5.7	4.8	3.1	2.8	1.8
Return Period > 30 Years	4.3	7.3	16.1	11.6	21.7	10.0	9.0	6.0	5.2	3.5	3.0	2.3

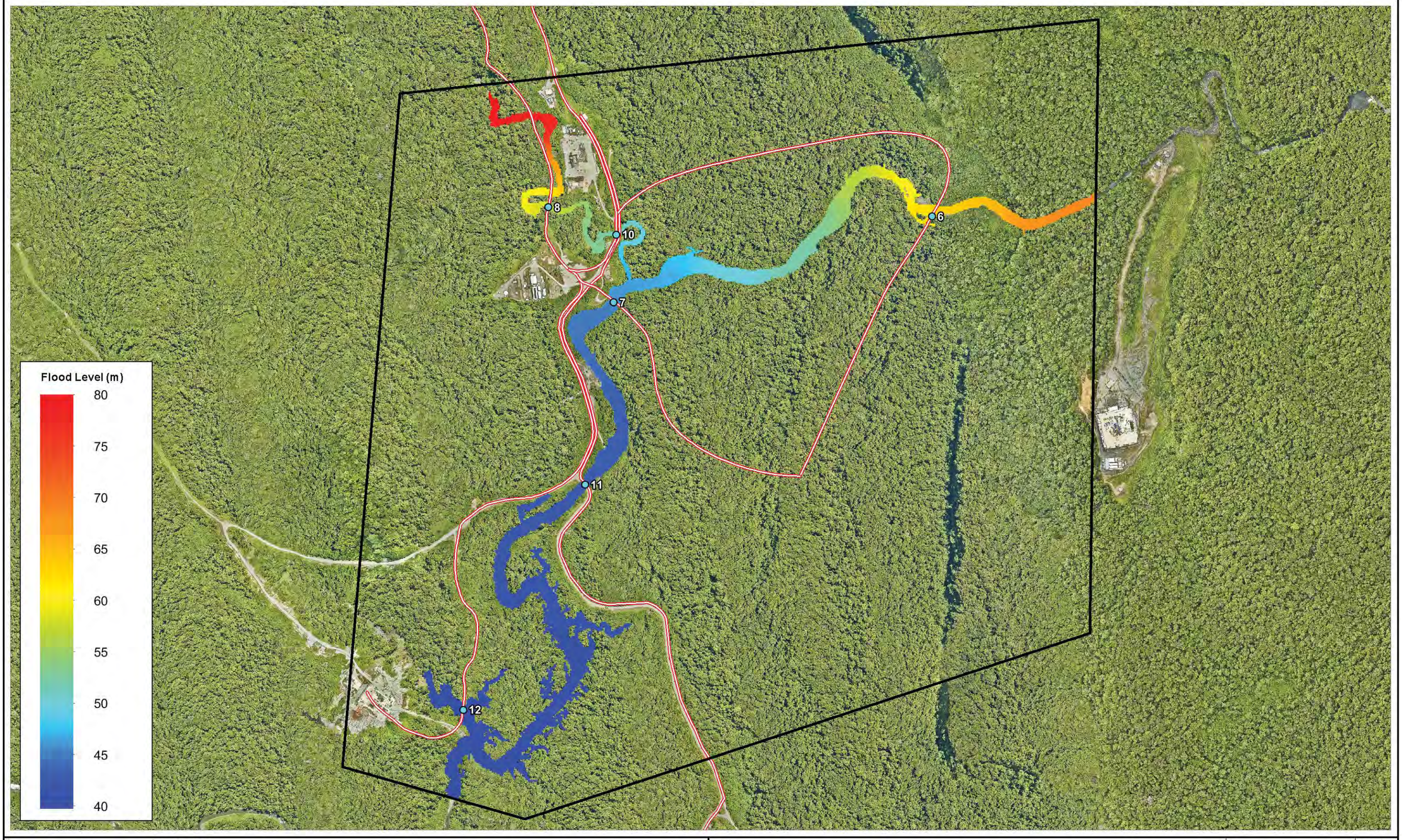
Note: Storm temporal patterns adopted from "Australian Rainfall and Runoff" (IE Aust, 1987)

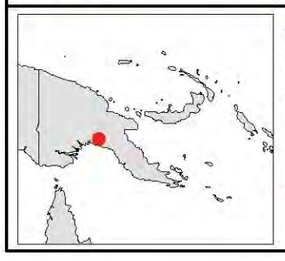
TABLE 4.3 - DESIGN STORM TEMPORAL PATTERNS FOR DURATIONS OF 2 HOURS AND LONGER

Storm Duration (h)	Time Increment (h)	PERCENTAGE OF TOTAL STORM RAINFALL IN EACH TIME INCREMENT																						
		Time Increment Number																						
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2	0.25	3.0	11.9	29.7	20.8	9.9	11.9	9.9	3.0															
3	0.5	6.0	22.0	34.0	22.0	12.0	4.0																	
4	0.5	5.8	9.6	20.2	30.8	13.5	8.7	4.8	6.7															
6	1	6.3	20.8	36.5	22.9	8.3	5.2																	
9	1	7.8	9.7	3.9	16.5	28.2	14.6	9.7	2.9	6.8														
12	1	4.2	8.3	19.8	13.5	6.3	7.3	5.2	5.2	8.3	9.4	7.3	5.2											
24	1	2.0	2.9	2.0	2.9	3.9	1.0	1.0	2.9	3.9	2.0	17.6	12.7	7.8	2.9	4.9	5.9	5.9	2.9	3.9	3.9	2.0	2.9	1.0	1.0

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Appendix D Hydraulic Modeling Results





LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:
Model S1 Flood Levels - 10 year event

Figure: D-1

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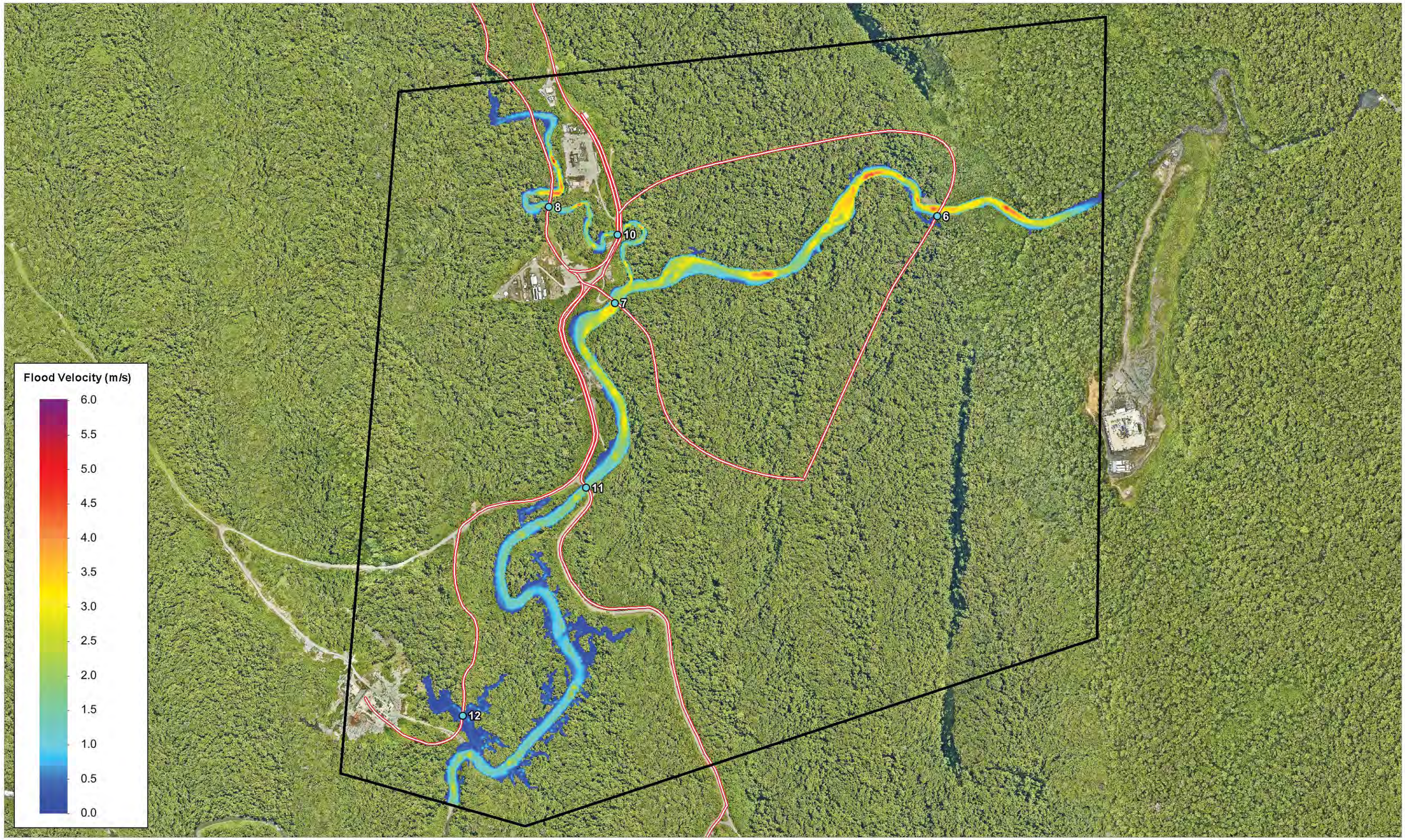
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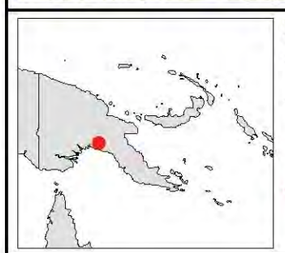
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S1 Flood Velocity - 10 year event

Figure: D-2

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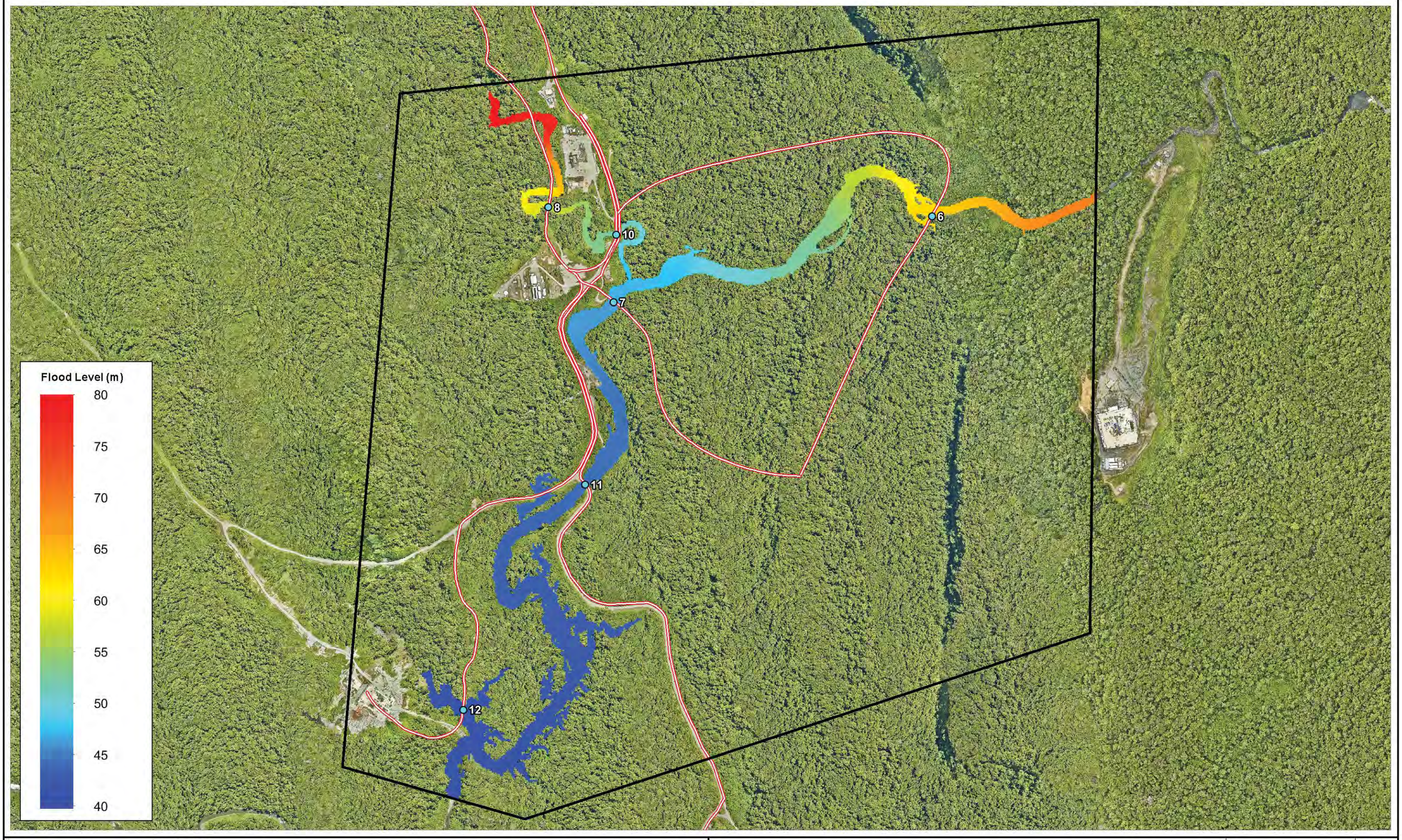
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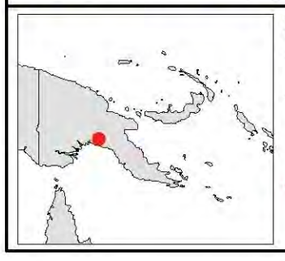
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:
Model S1 Flood Levels - 50 year event

Figure: D-3

Rev: A

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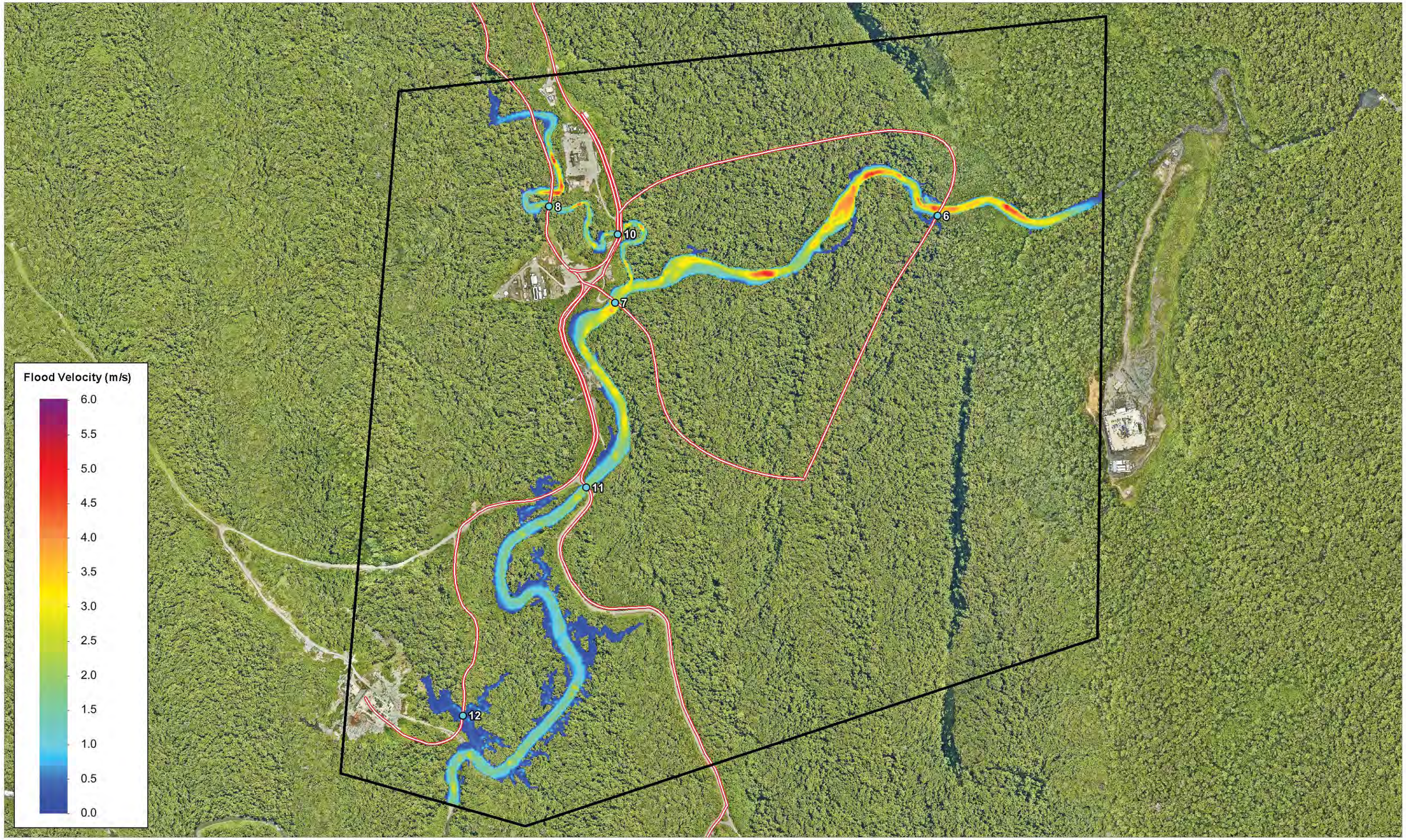
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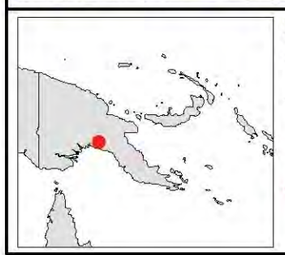
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S1 Flood Velocity - 50 year event

Figure: D-4

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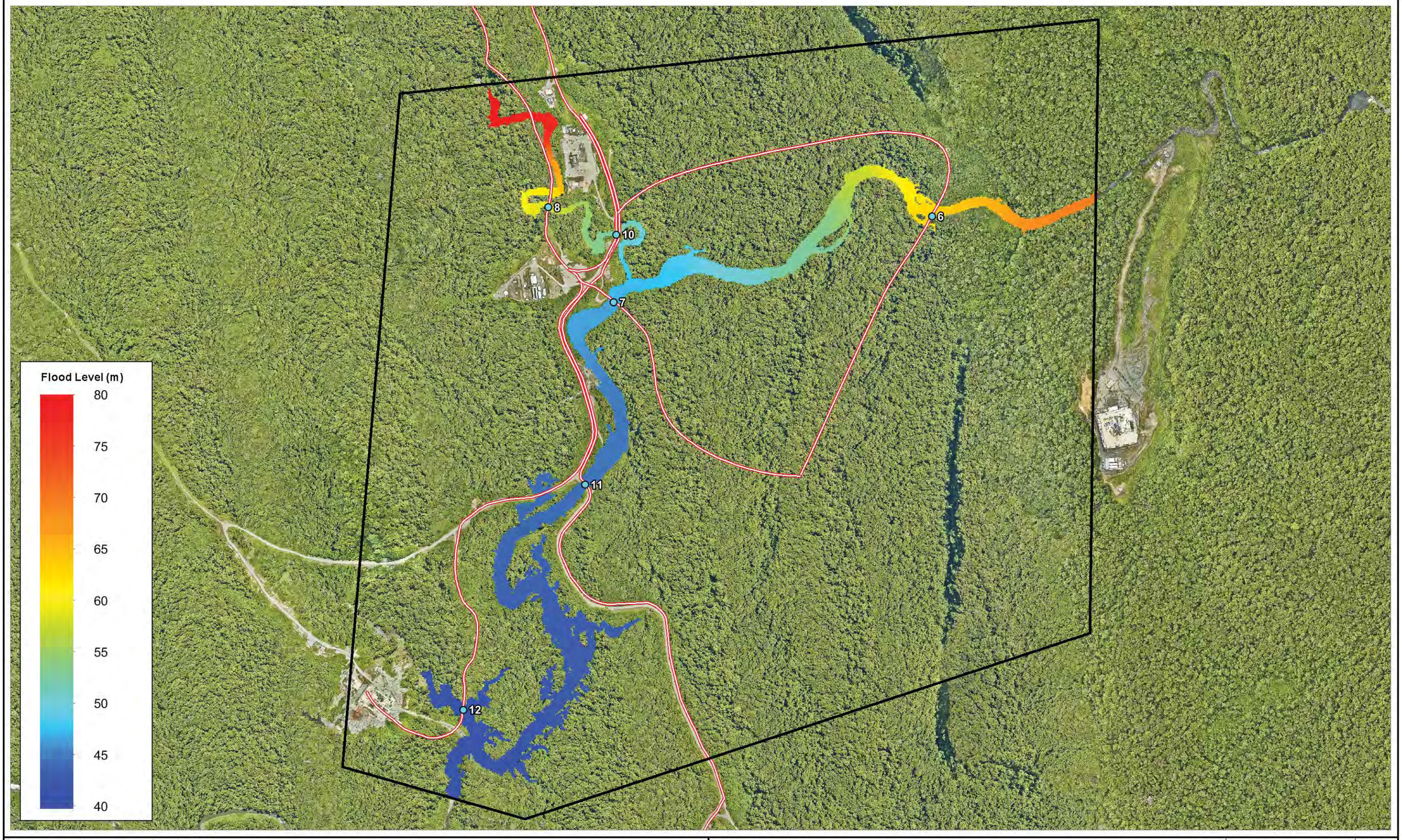
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:
Model S1 Flood Levels - 10 year event

Figure: D-5

Rev: A

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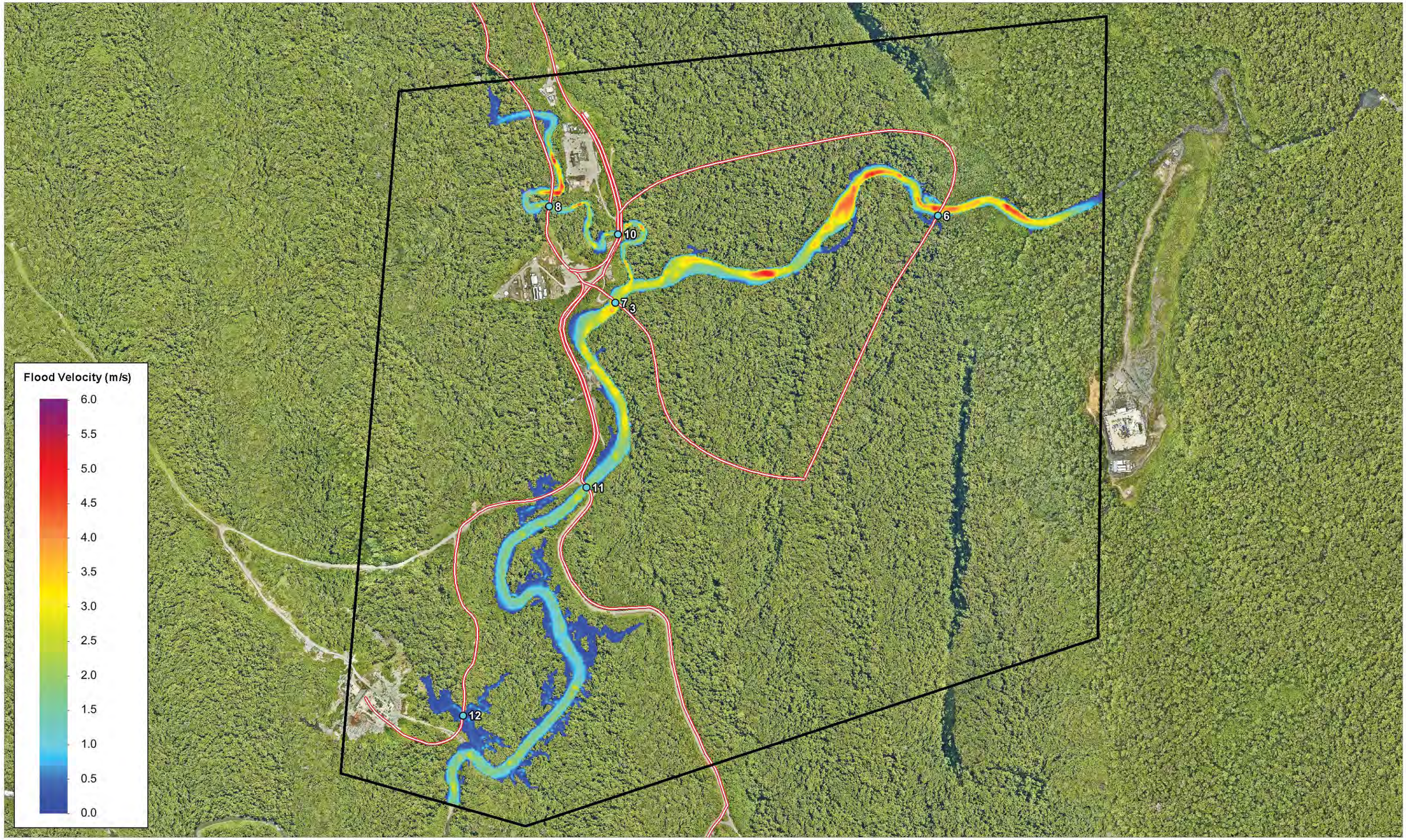
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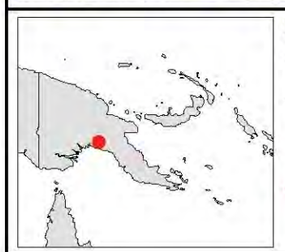
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S1 Flood Velocity - 100 year event

Figure: D-6

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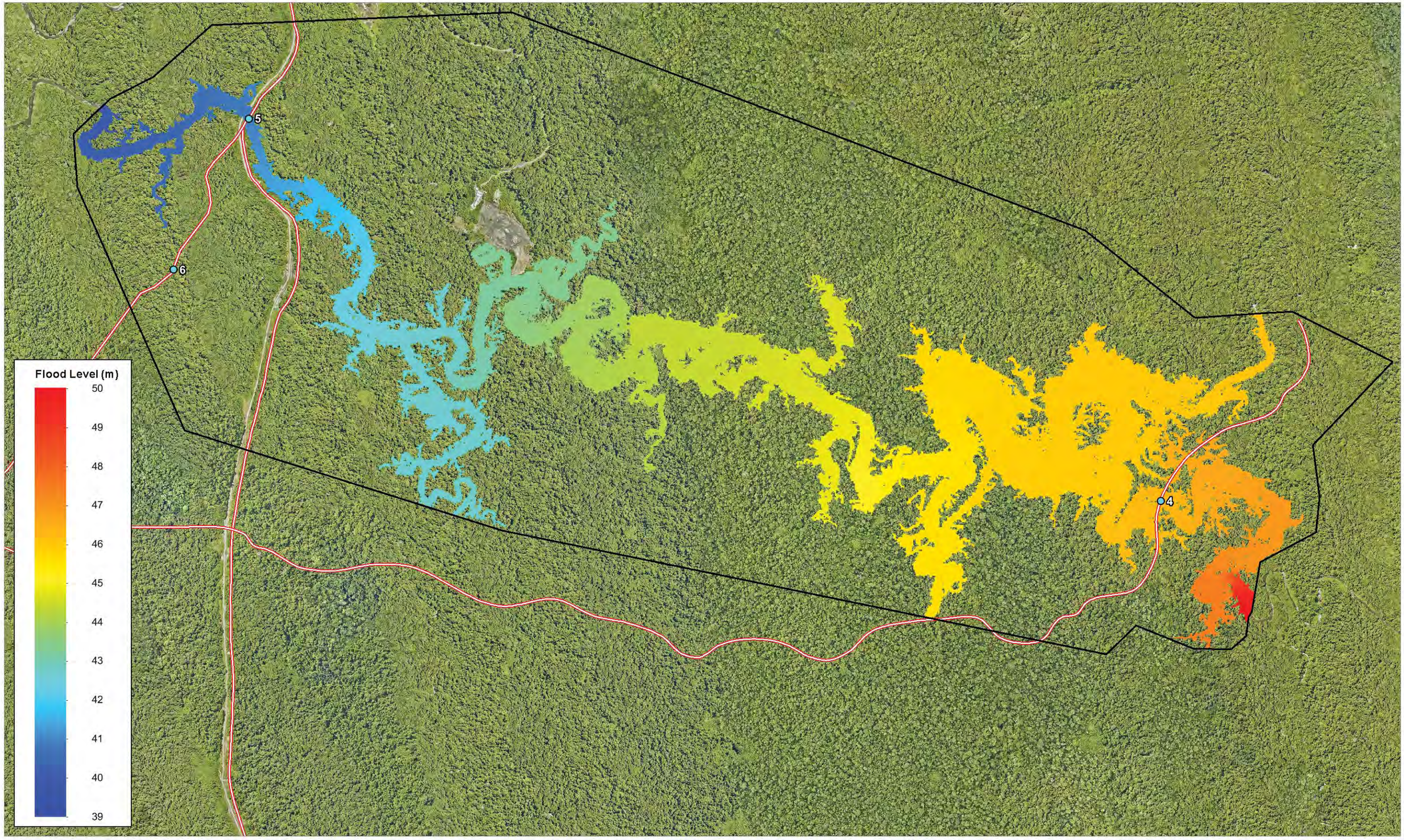
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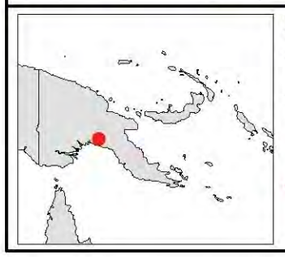
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S2 Flood Levels - 10 year event

Figure: D-7

Rev: A

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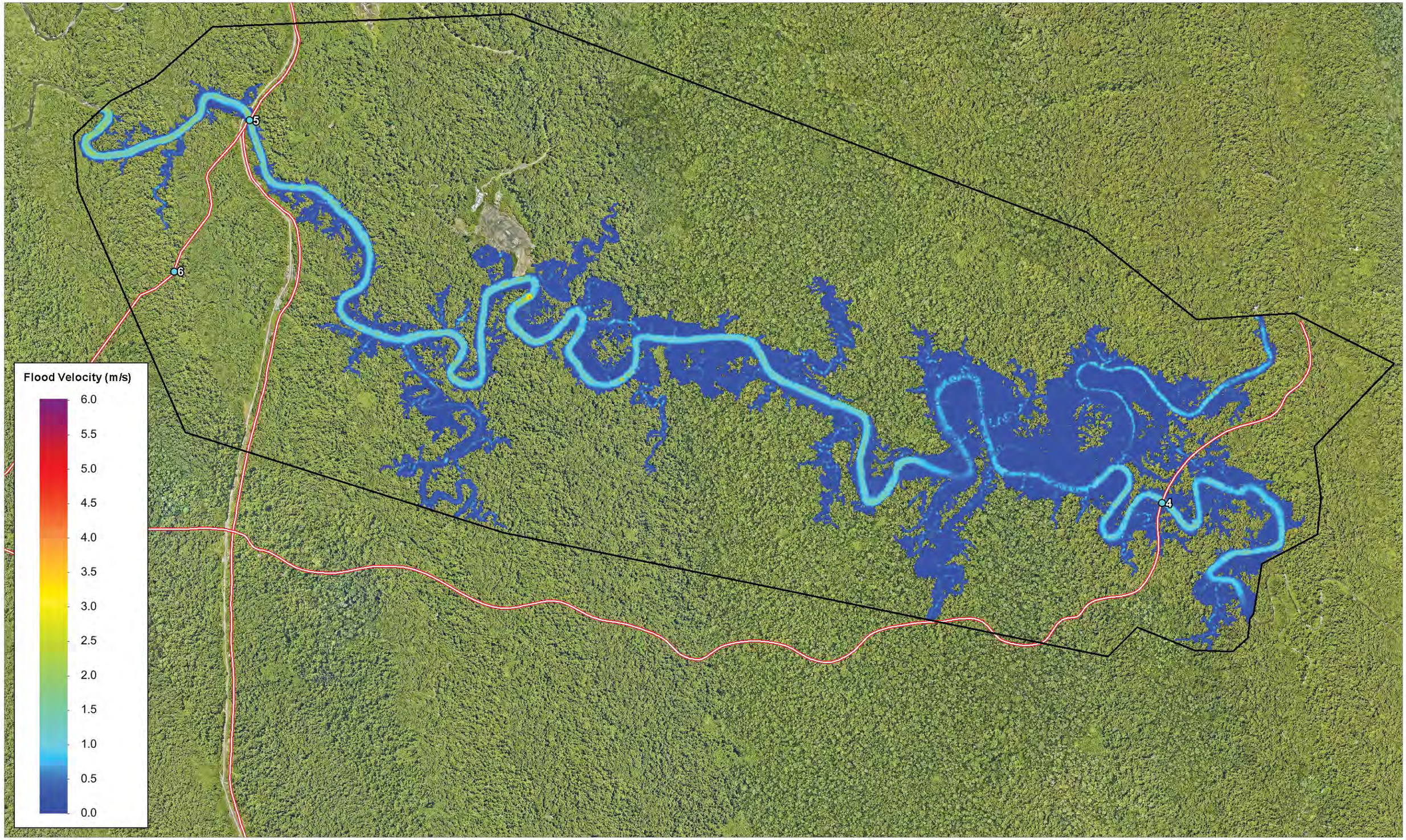
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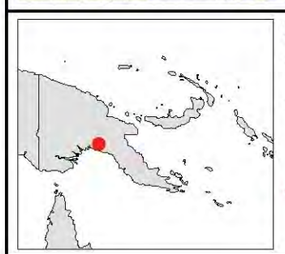
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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S2 Flood Velocity - 10 year event

Figure: D-8

Rev: A

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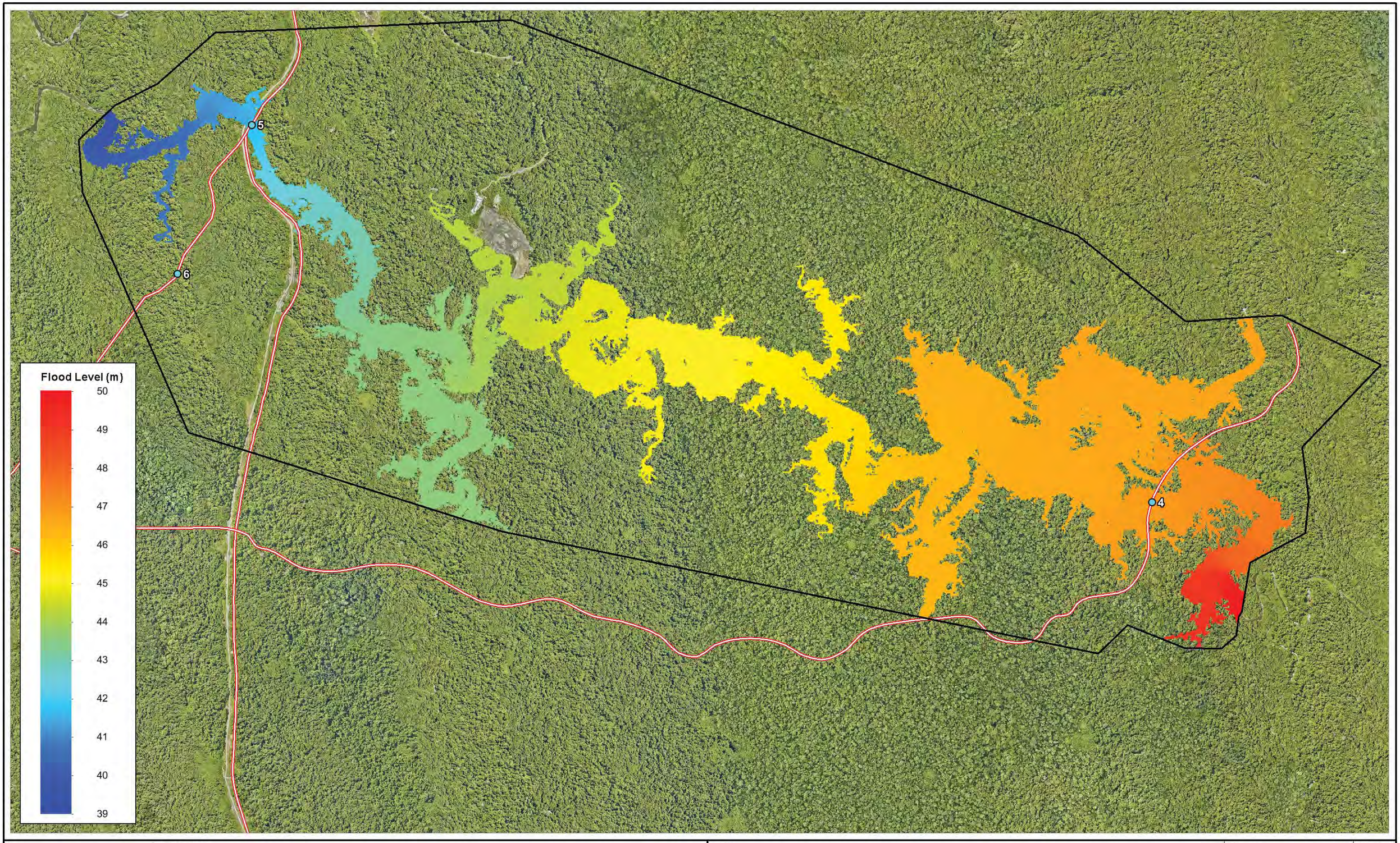
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:
Model S2 Flood Levels - 50 year event

Figure: D-9

Rev: A

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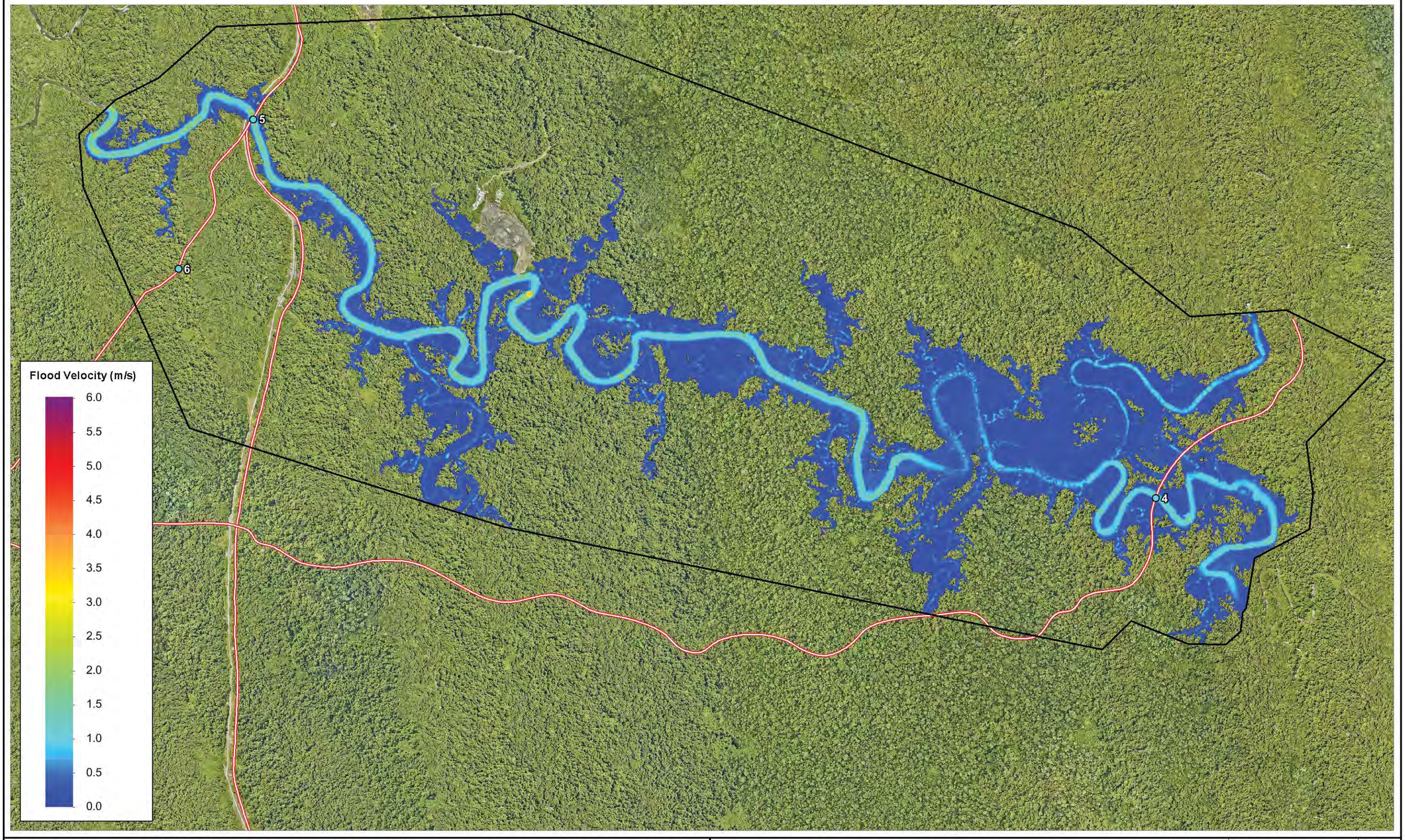
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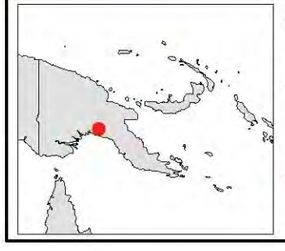
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:
Model S2 Flood Velocity - 50 year event

Figure: D-10

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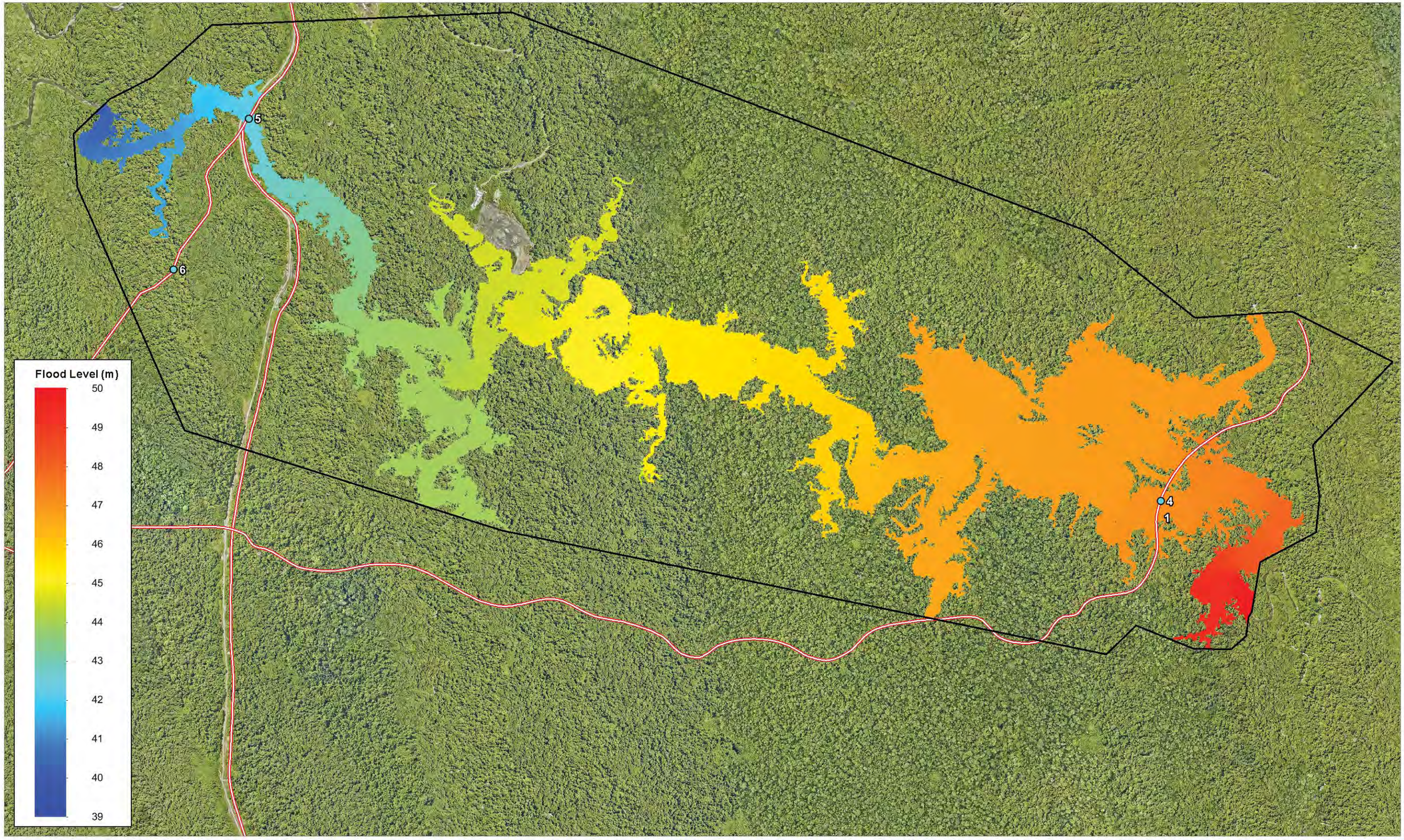
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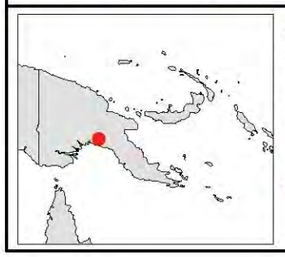
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S2 Flood Levels - 100 year event

Figure: D-11

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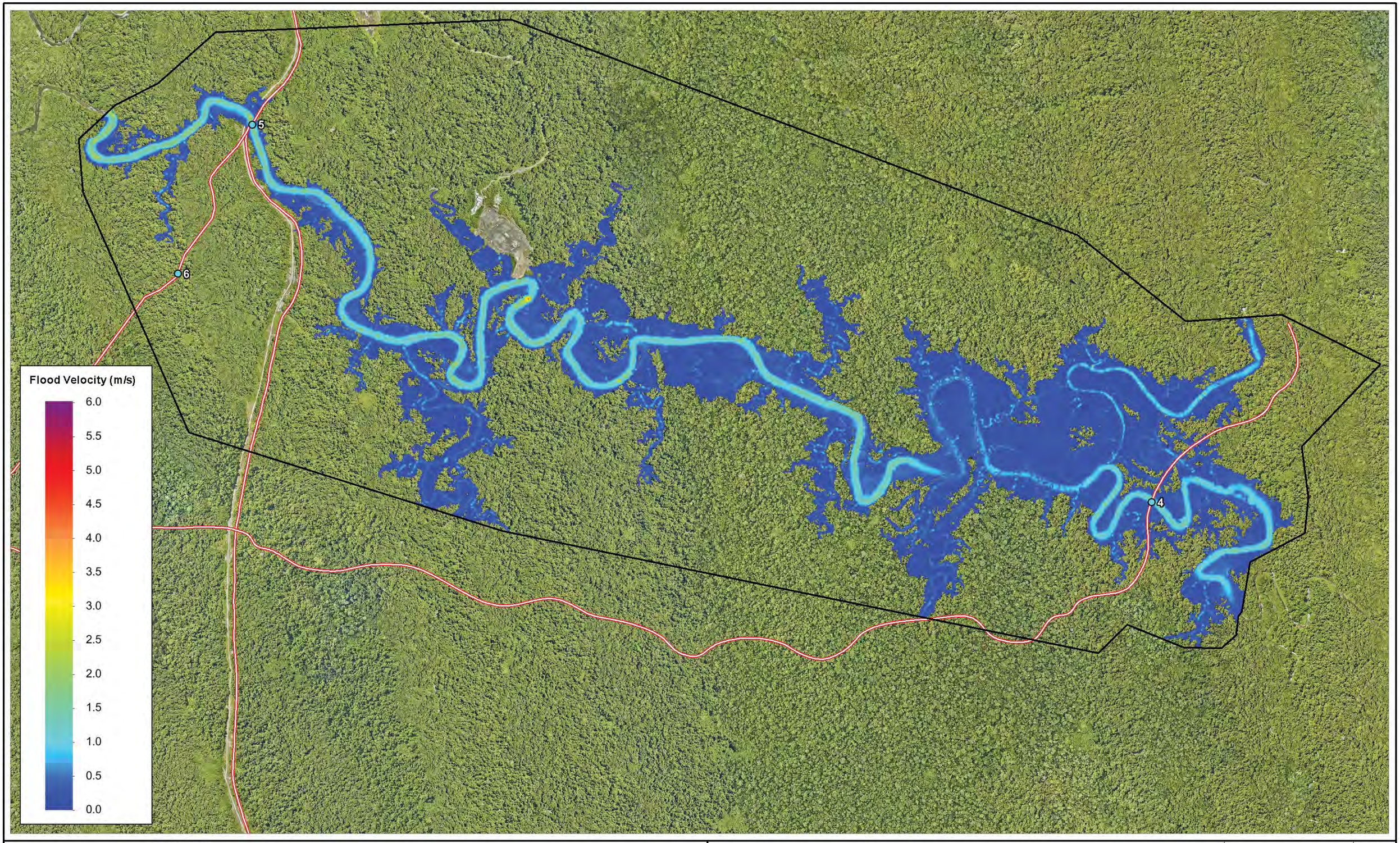
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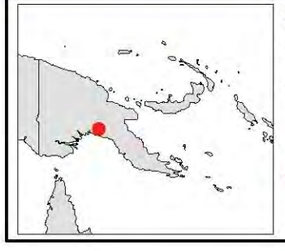
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:
Model S2 Flood Velocity - 100 year event

Figure: D-12

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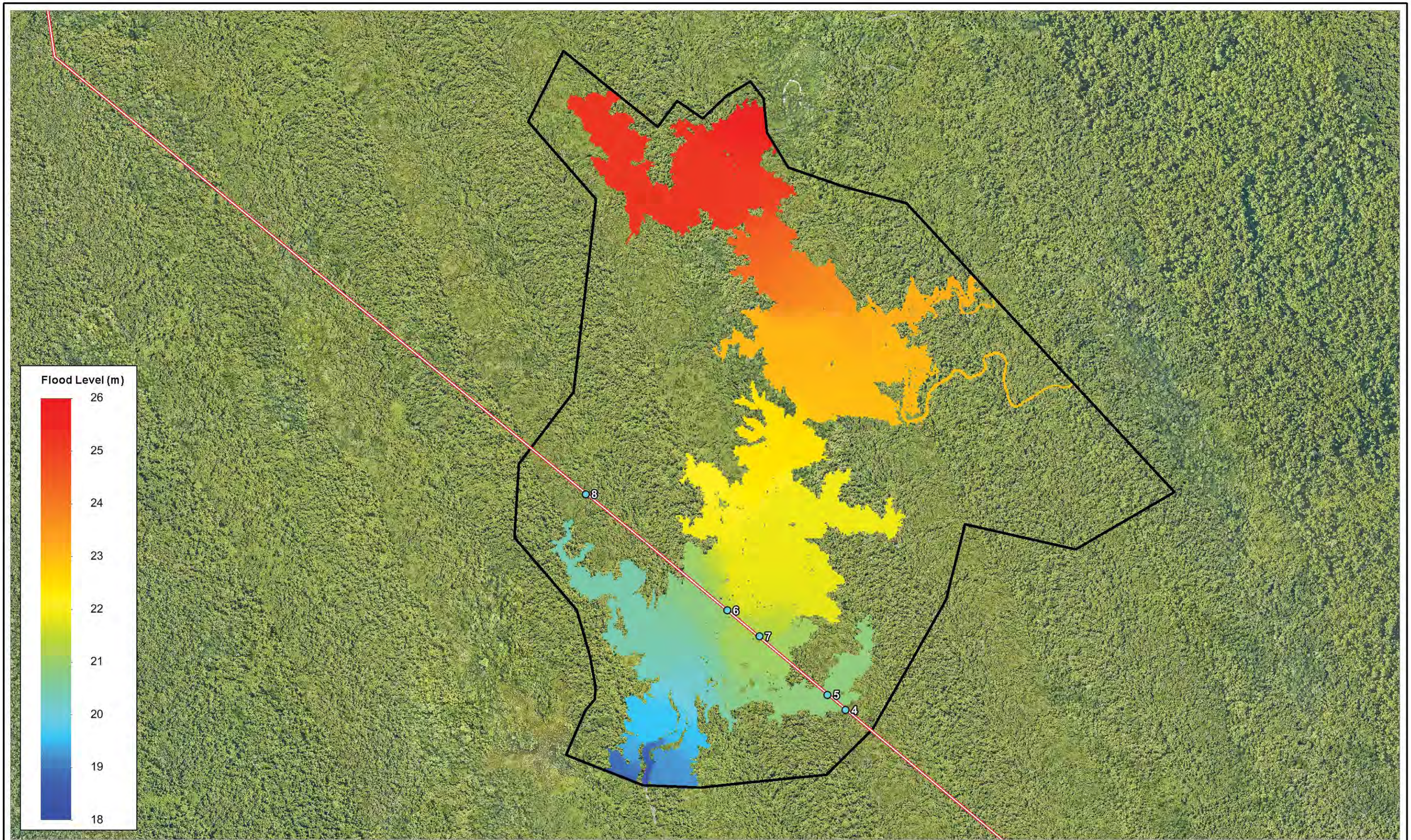
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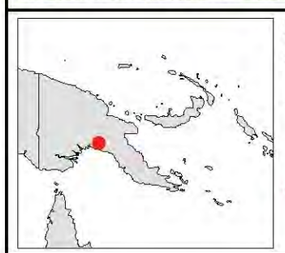
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Approx. Scale

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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S4 Flood Levels - 10 year event

Figure: D-13

Rev: A

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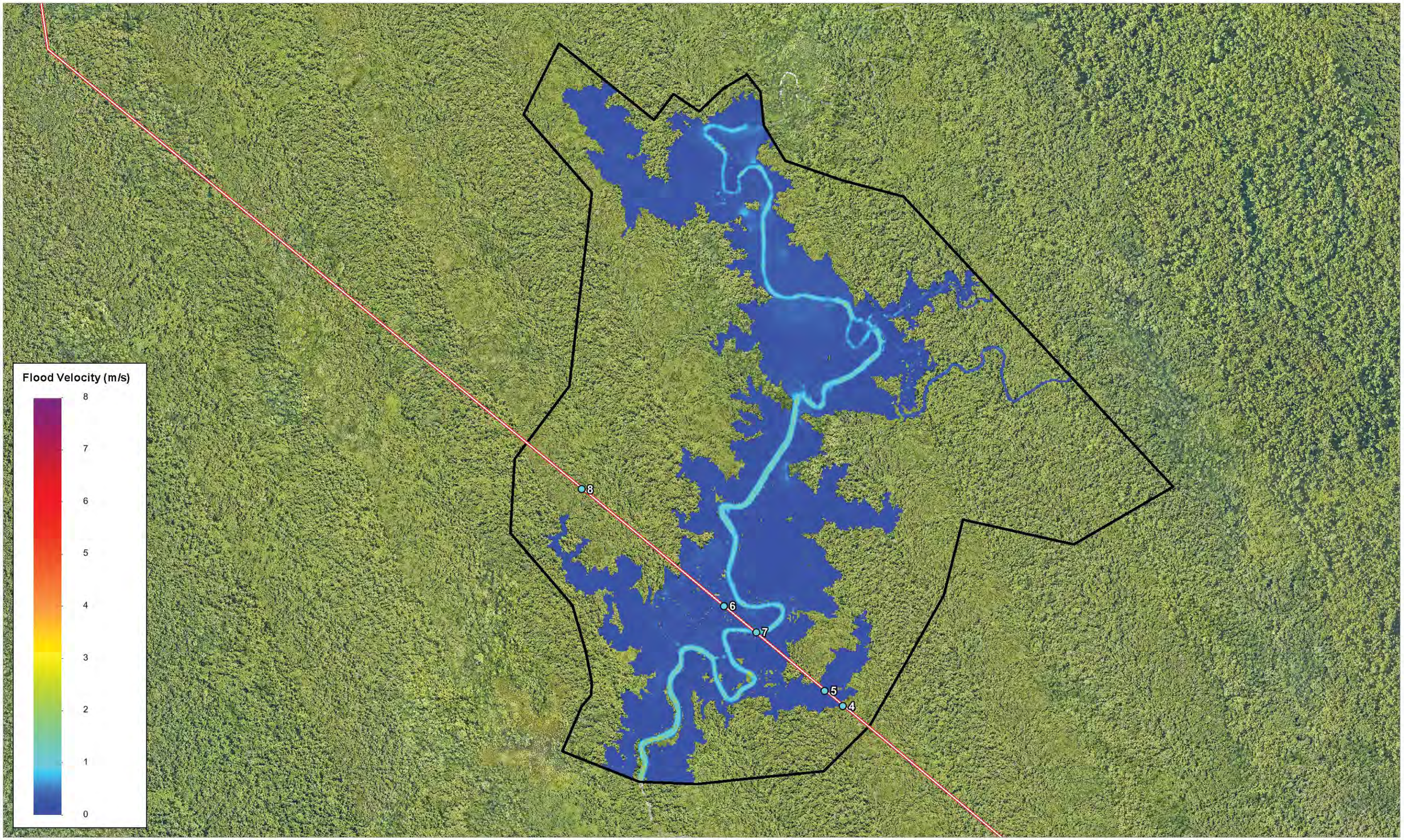
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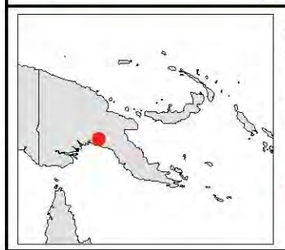
Approx. Scale

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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_019_170315_S4_h_10y.wor





LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S4 Flood Velocity - 10 year event

Figure: D-14

Rev: A

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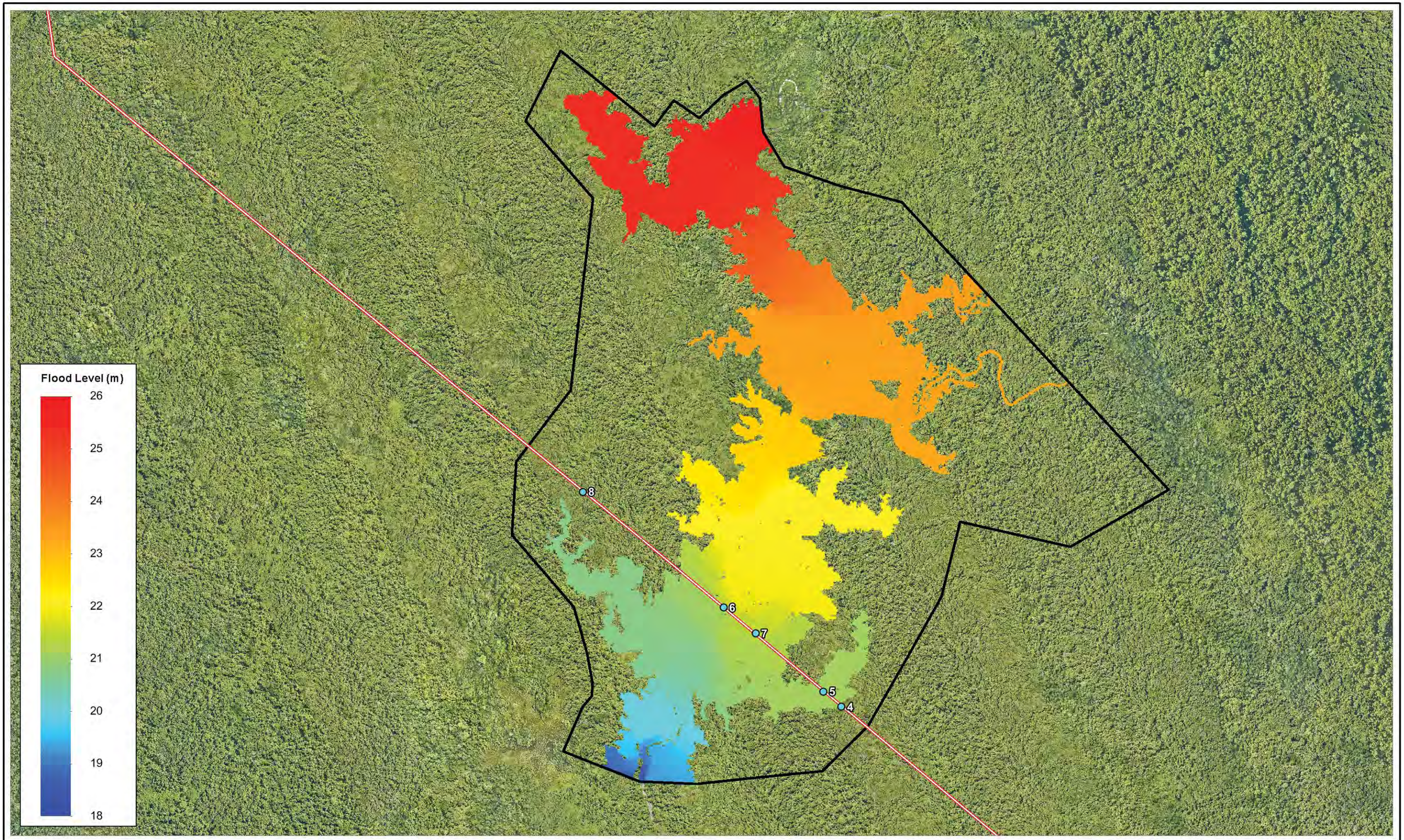
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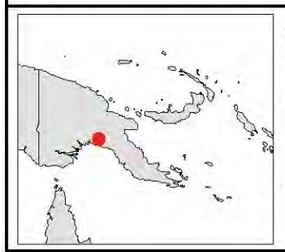
Approx. Scale

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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_020_170317_S4_v_10y.wor





LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S4 Flood Levels - 50 year event

Figure: D-15

Rev: A

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0 250 500m

Approx. Scale

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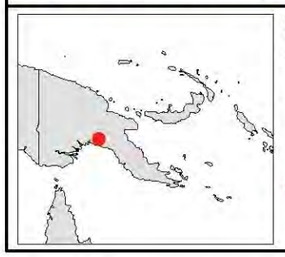
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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_021_170315_S4_h_50y.wor

Flood Velocity (m/s)

8
7
6
5
4
3
2
1
0

8
6
7
5
4



LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S4 Flood Velocity - 50 year event

Figure: D-16

Rev: A

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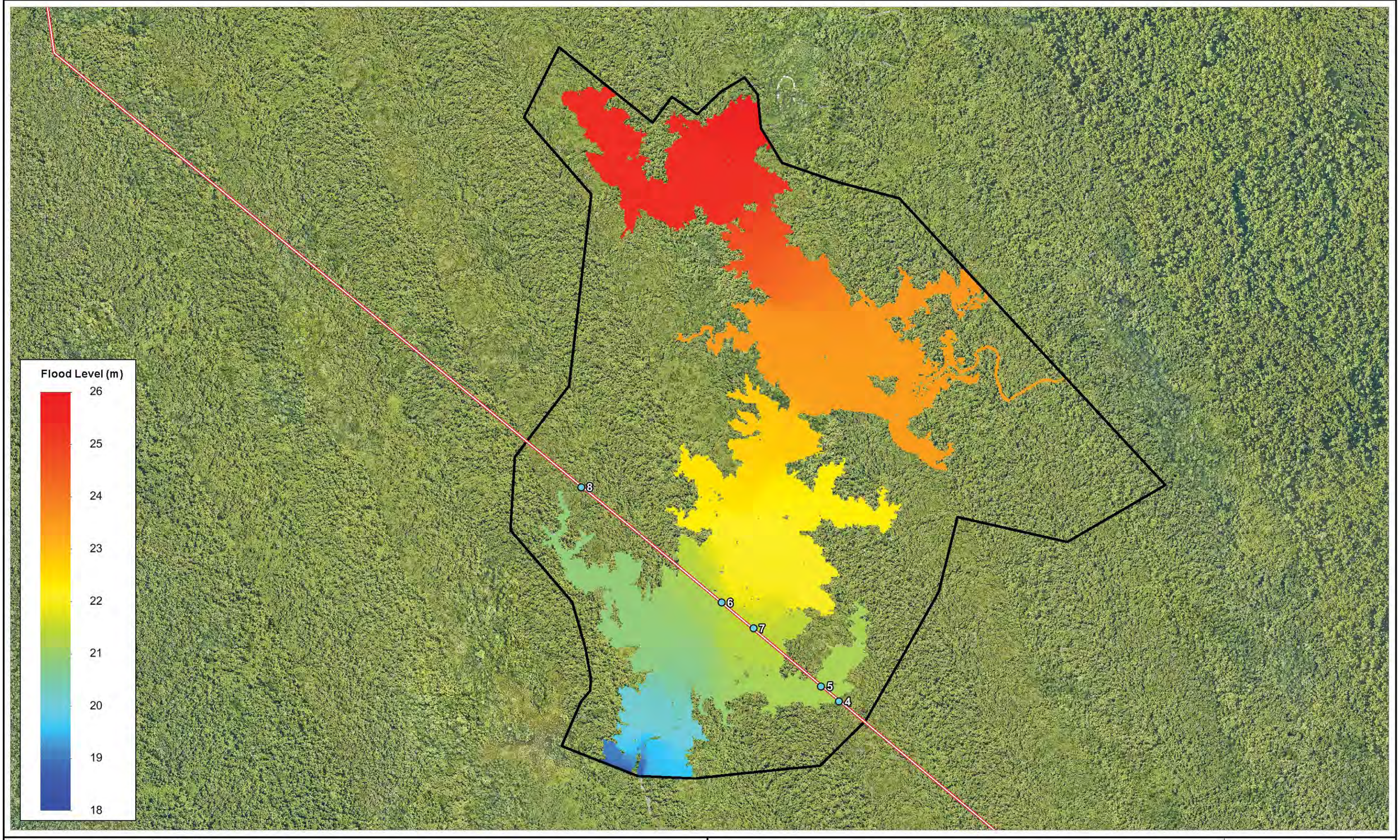
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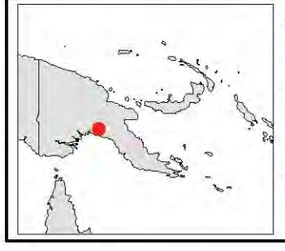
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:
Model S4 Flood Levels - 100 year event

Figure: D-17

Rev: A

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N

0 250 500m

Approx. Scale

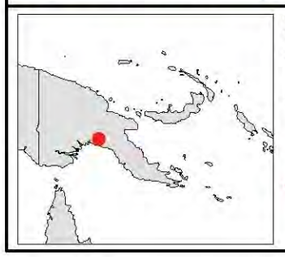
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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_023_170315_S4_h_100y.wor

Flood Velocity (m/s)

8
7
6
5
4
3
2
1
0

8
6
7
5
4



LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S4 Flood Velocity - 100 year event

Figure: D-18

Rev: A

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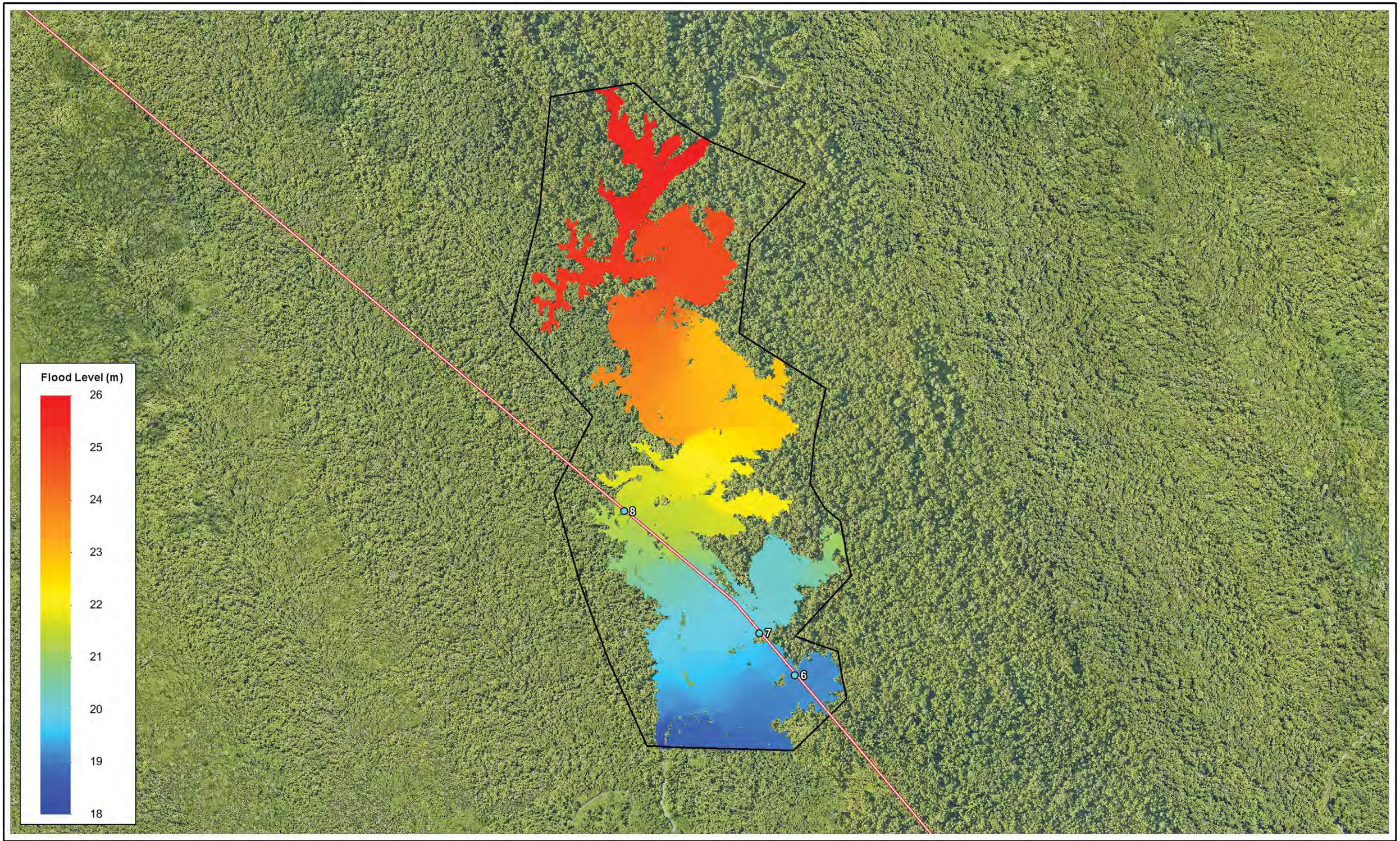
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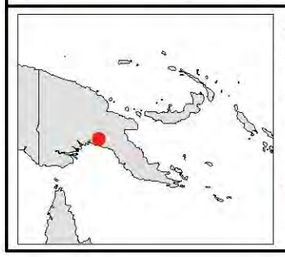
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S5 Flood Levels - 10 year event

Figure: D-19

Rev: A

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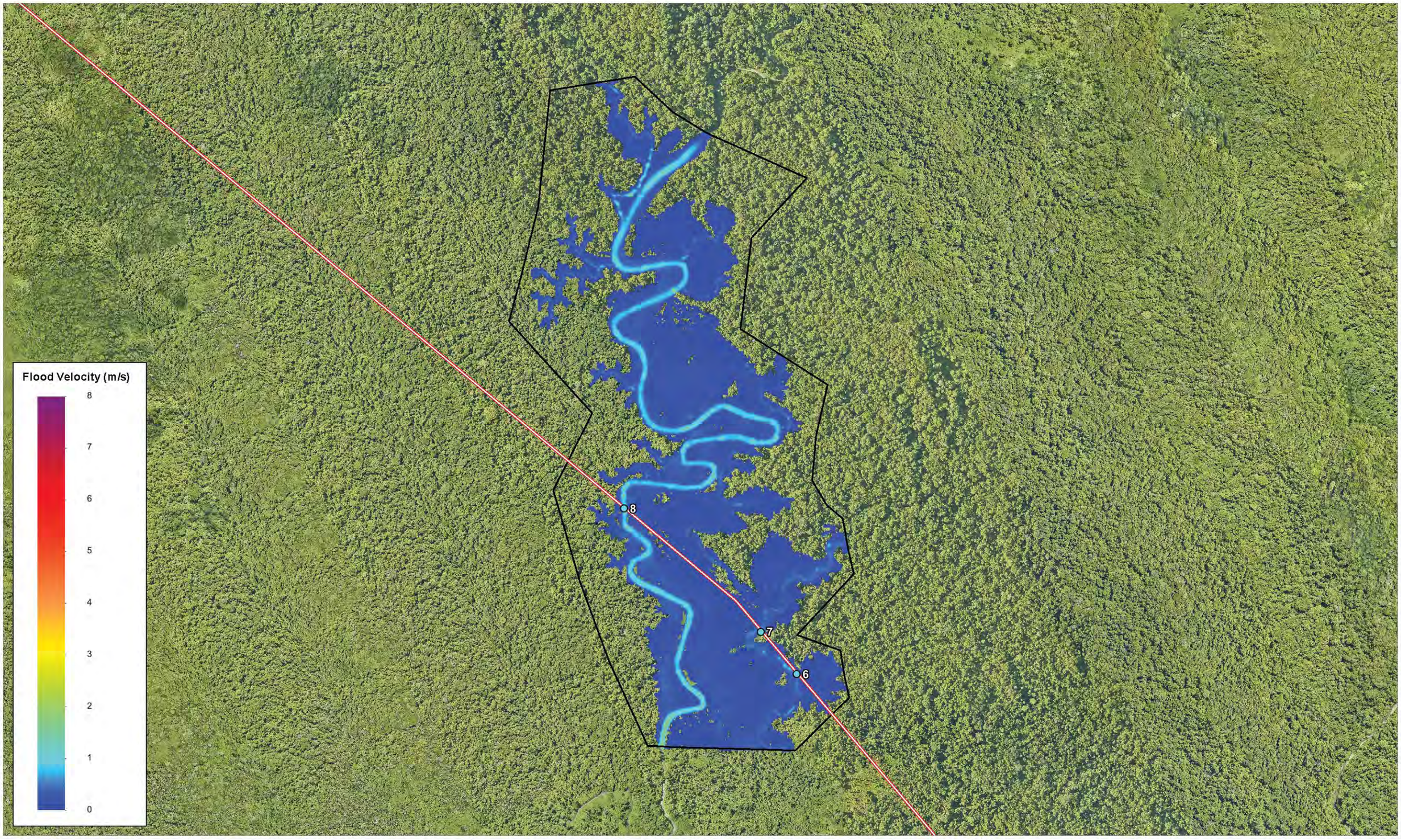
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Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S5 Flood Velocity - 10 year event

Figure: D-20

Rev: A

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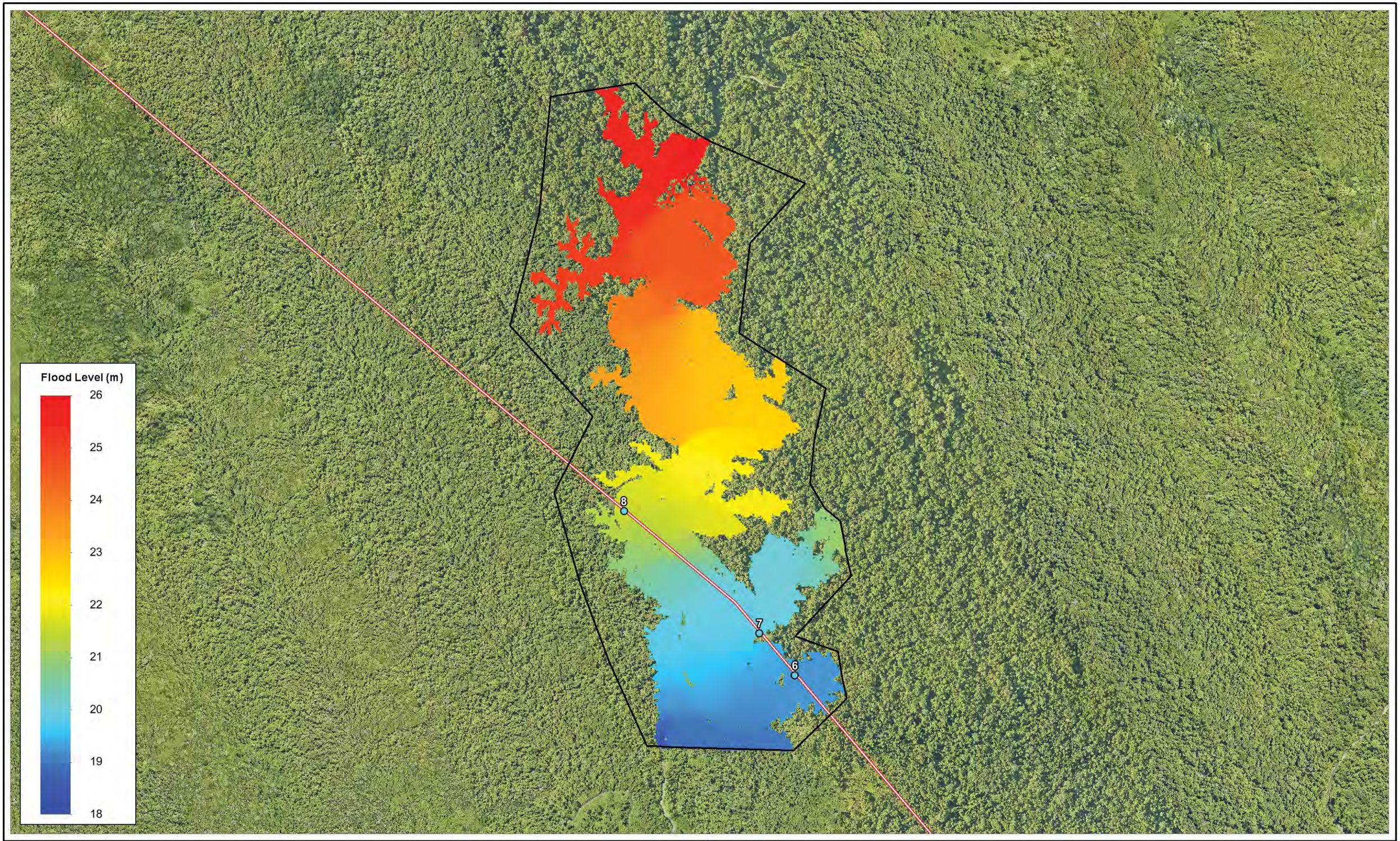
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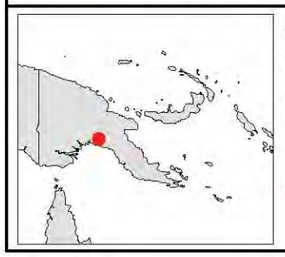
Approx. Scale

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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S5 Flood Levels - 50 year event

Figure: D-21

Rev: A

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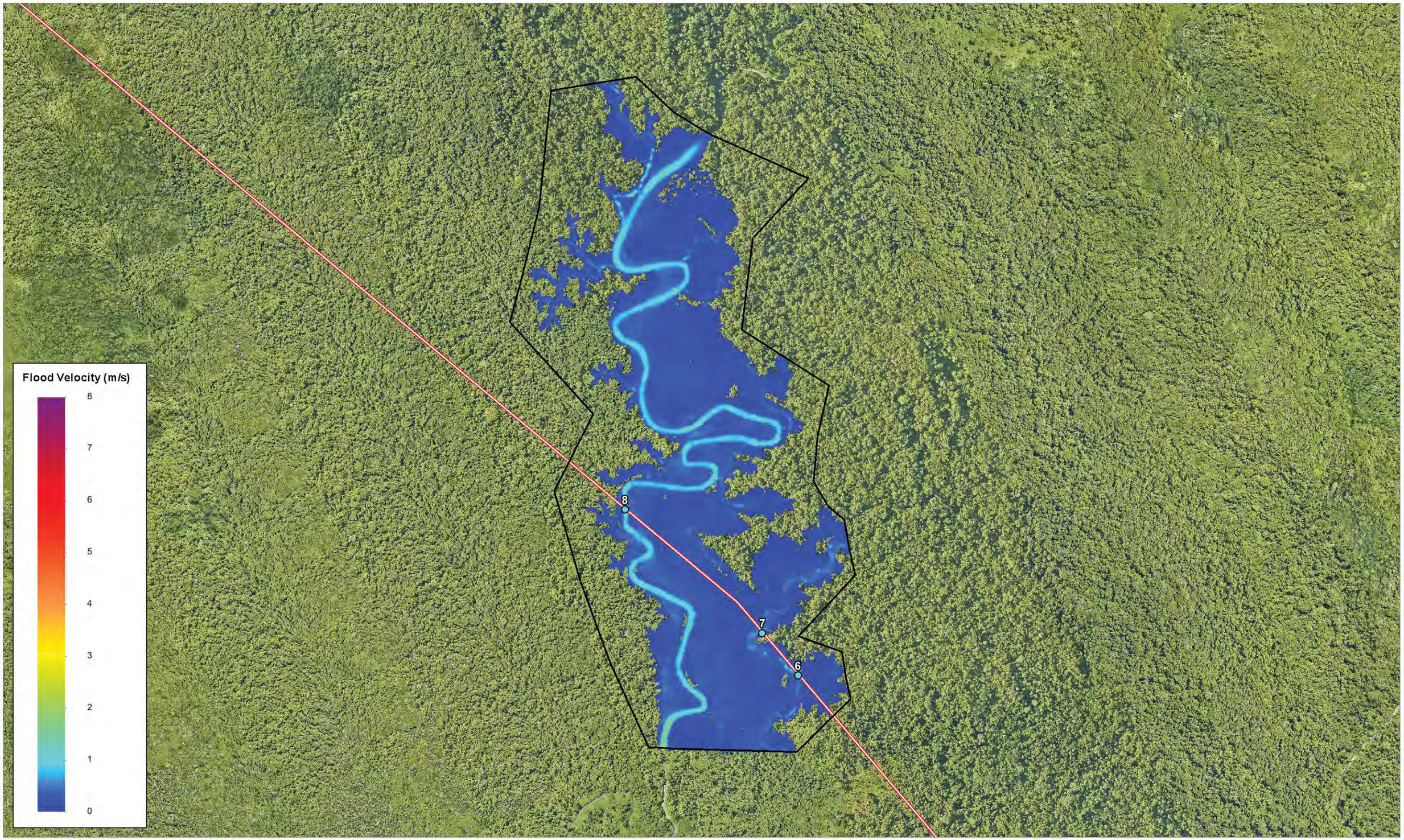
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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S5 Flood Velocity - 50 year event

Figure: D-22

Rev: A

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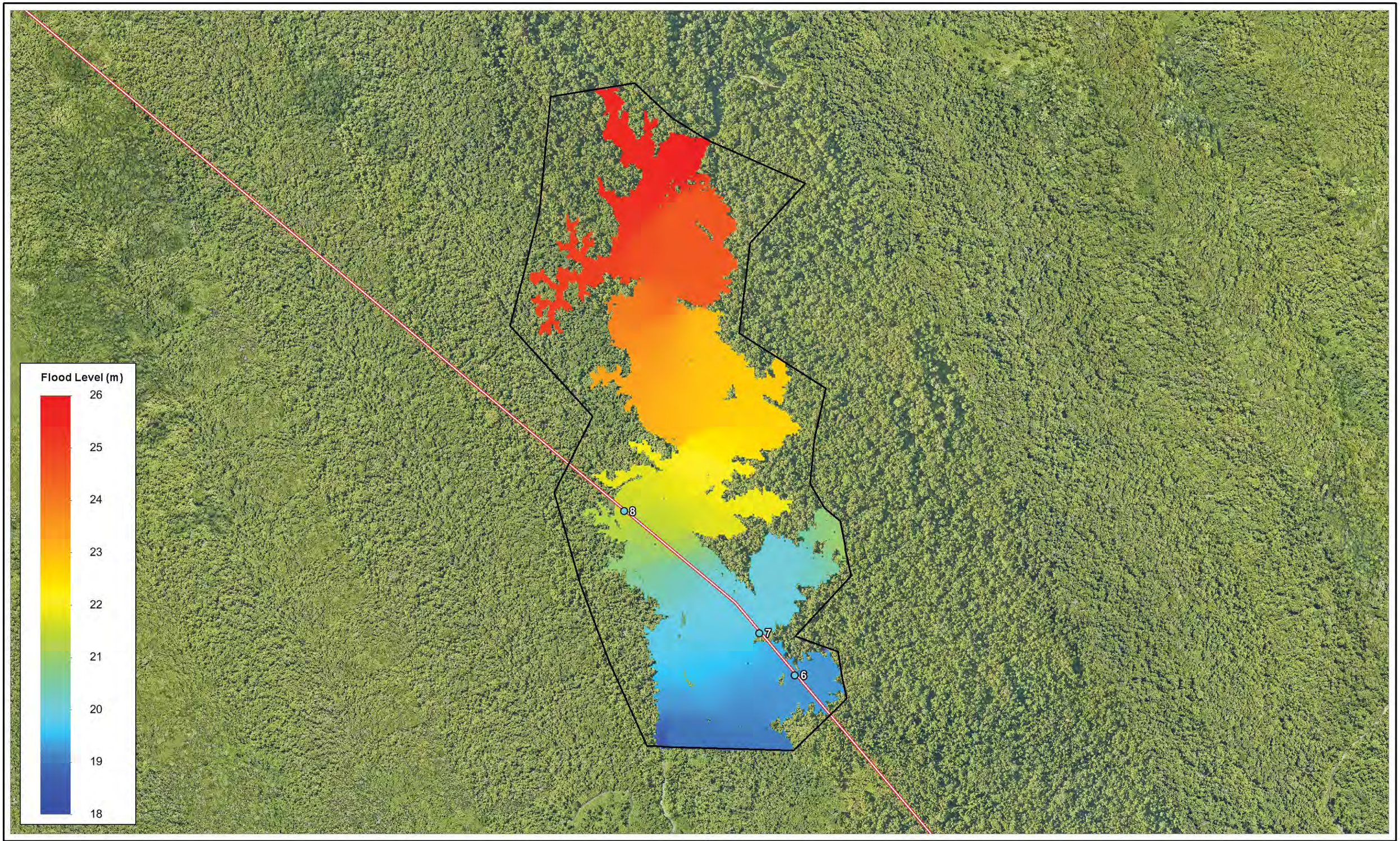
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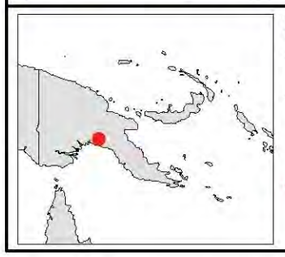
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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S5 Flood Levels - 100 year event

Figure: D-23

Rev: A

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N

0 250 500m

Approx. Scale

BMT WBM

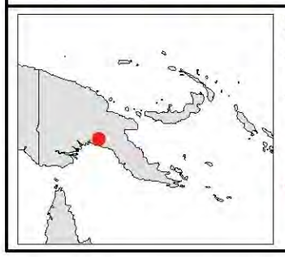
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Flood Velocity (m/s)

8
7
6
5
4
3
2
1
0

8
7
6



LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S5 Flood Velocity - 100 year event

Figure: D-24

Rev: A

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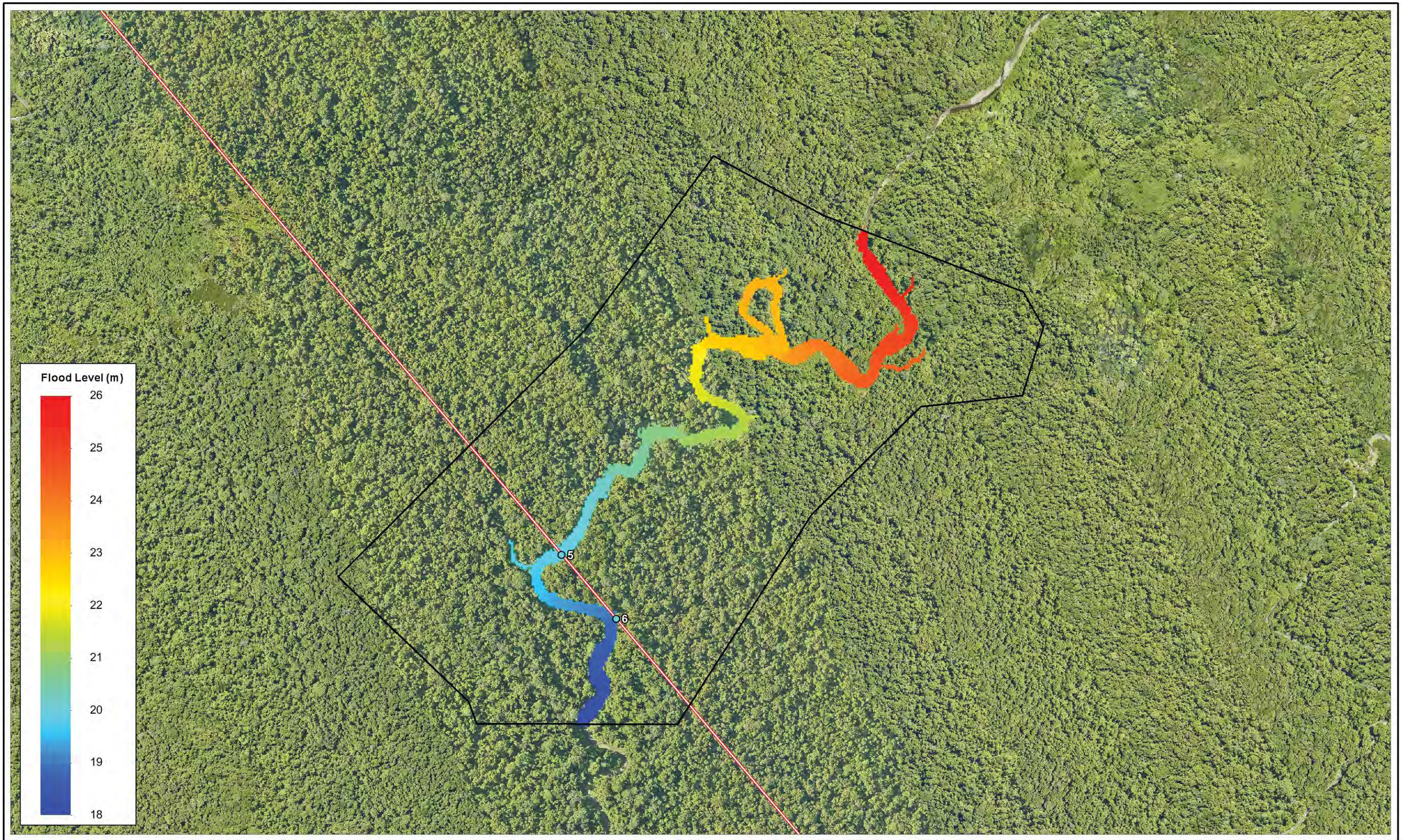
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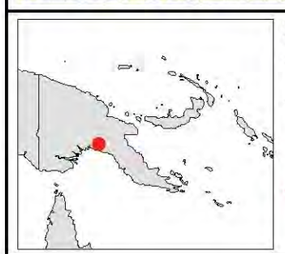
Approx. Scale

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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:
Model S6 Flood Levels - 10 year event

Figure: D-25

Rev: A

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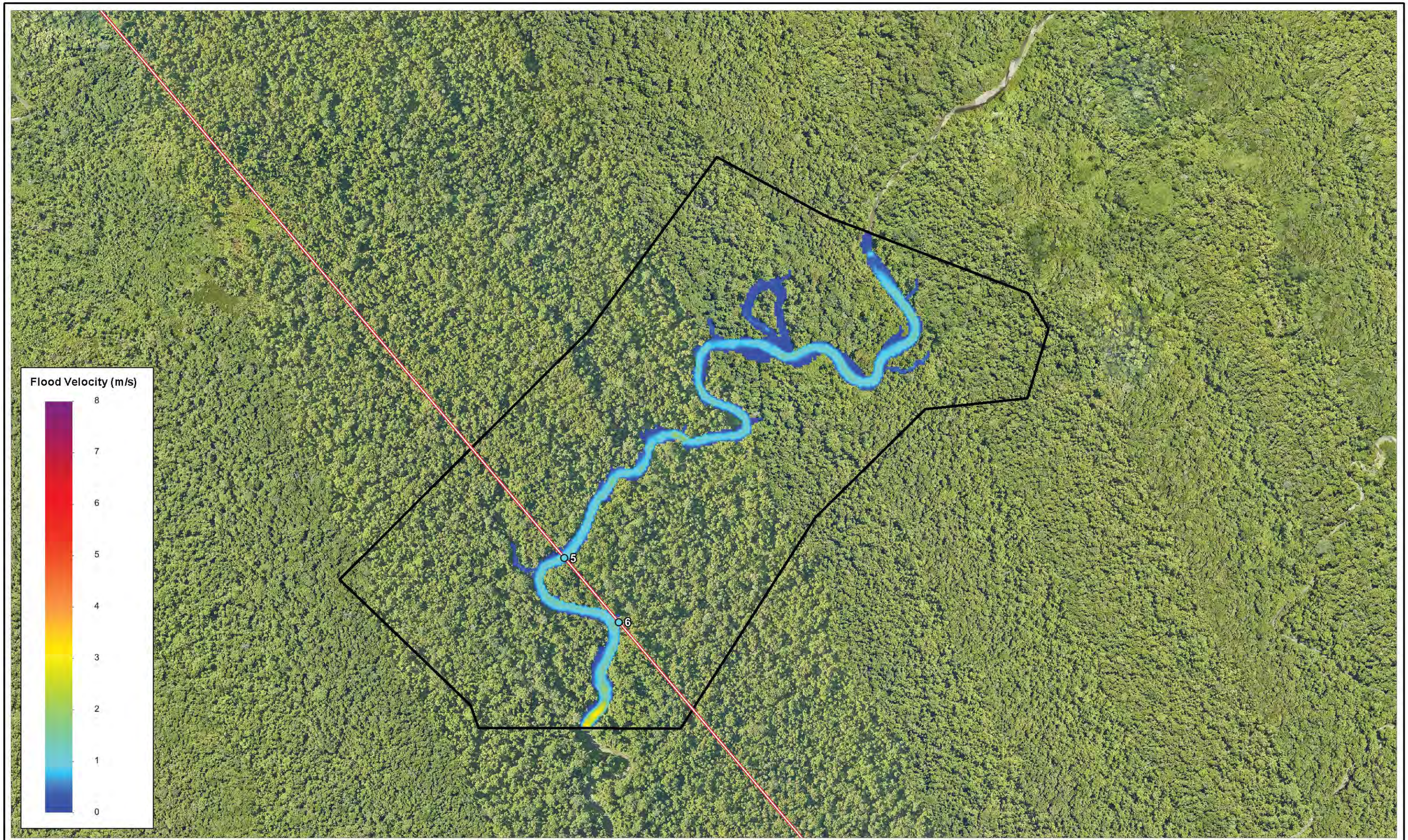
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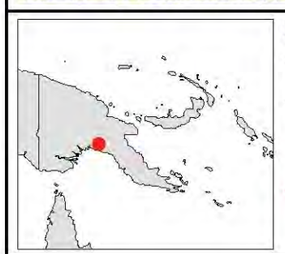
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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S6 Flood Velocity - 10 year event

Figure: D-26

Rev: A

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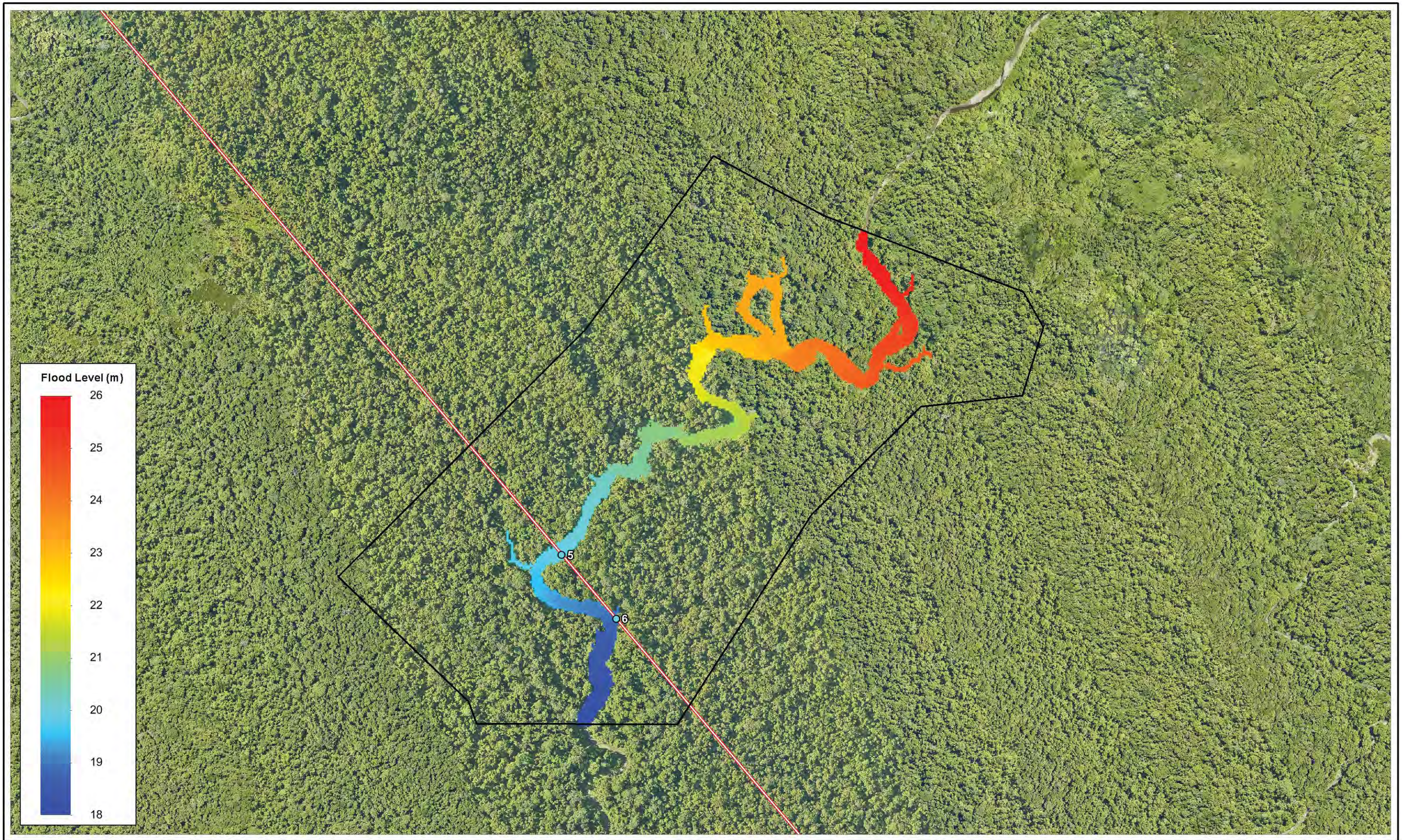
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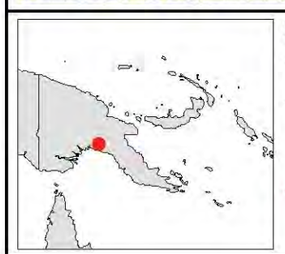
Approx. Scale

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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S6 Flood Levels - 50 year event

Figure: D-27

Rev: A

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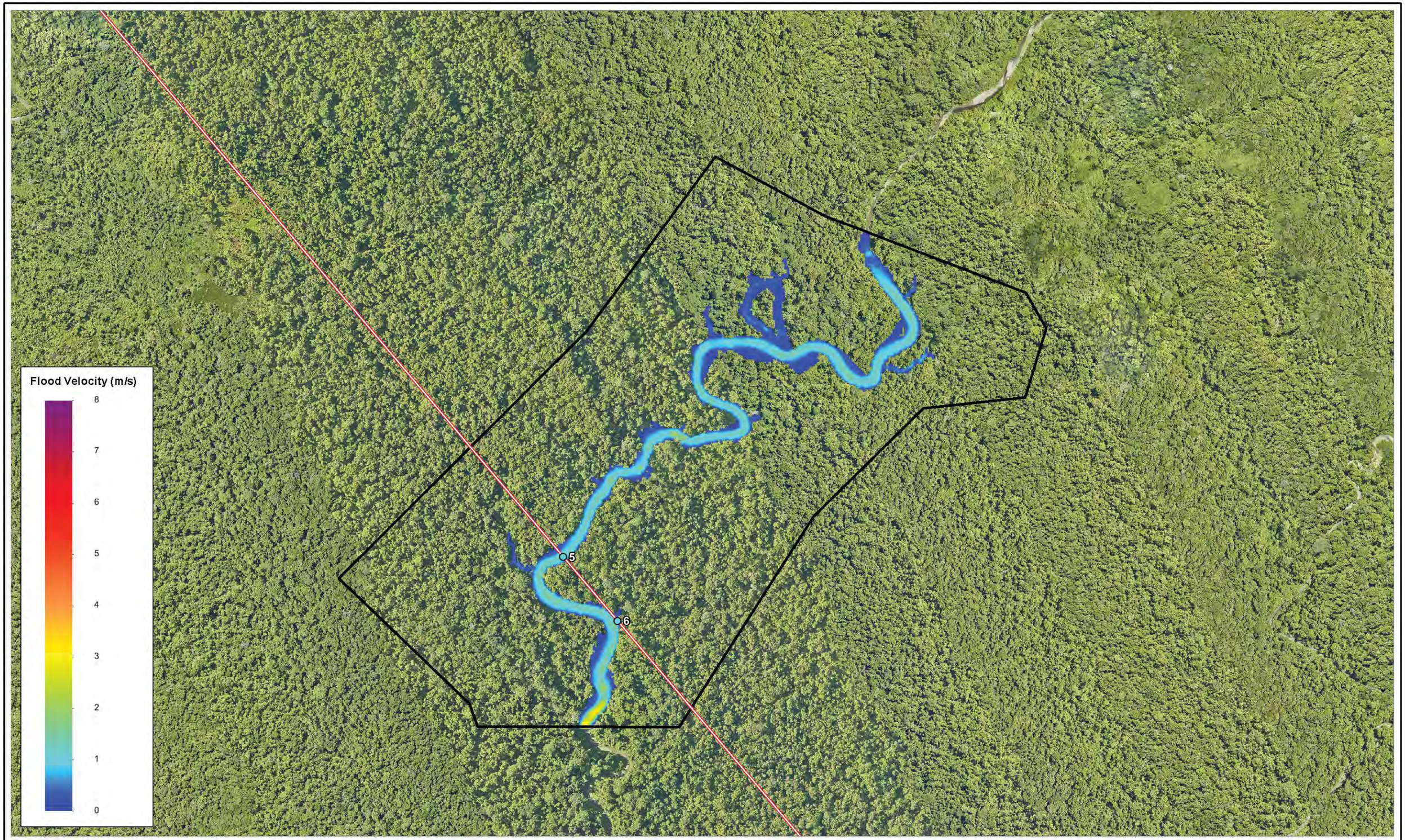
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Approx. Scale

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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S6 Flood Velocity - 50 year event

Figure: D-28

Rev: A

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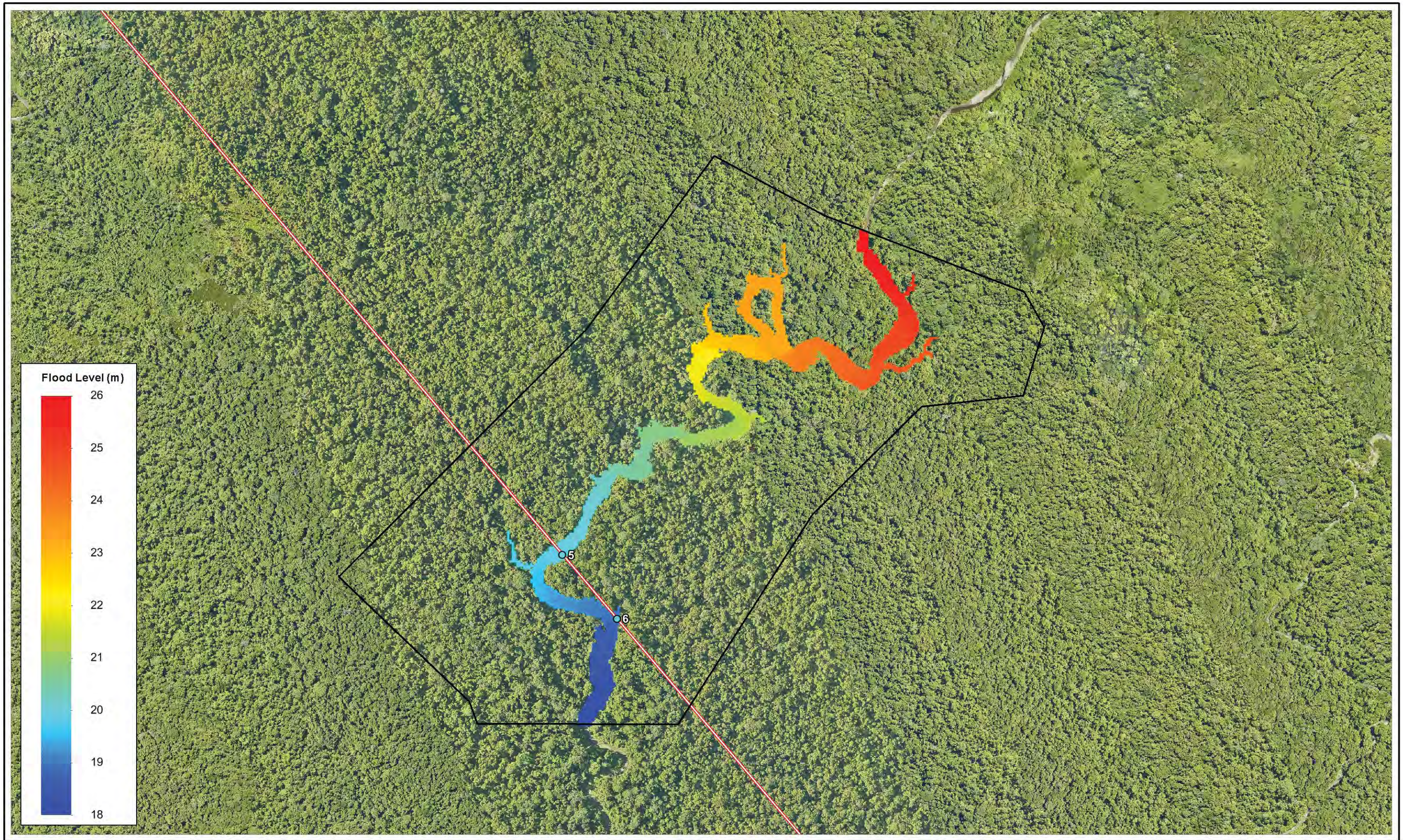
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Approx. Scale

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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S6 Flood Levels - 100 year event

Figure: D-29

Rev: A

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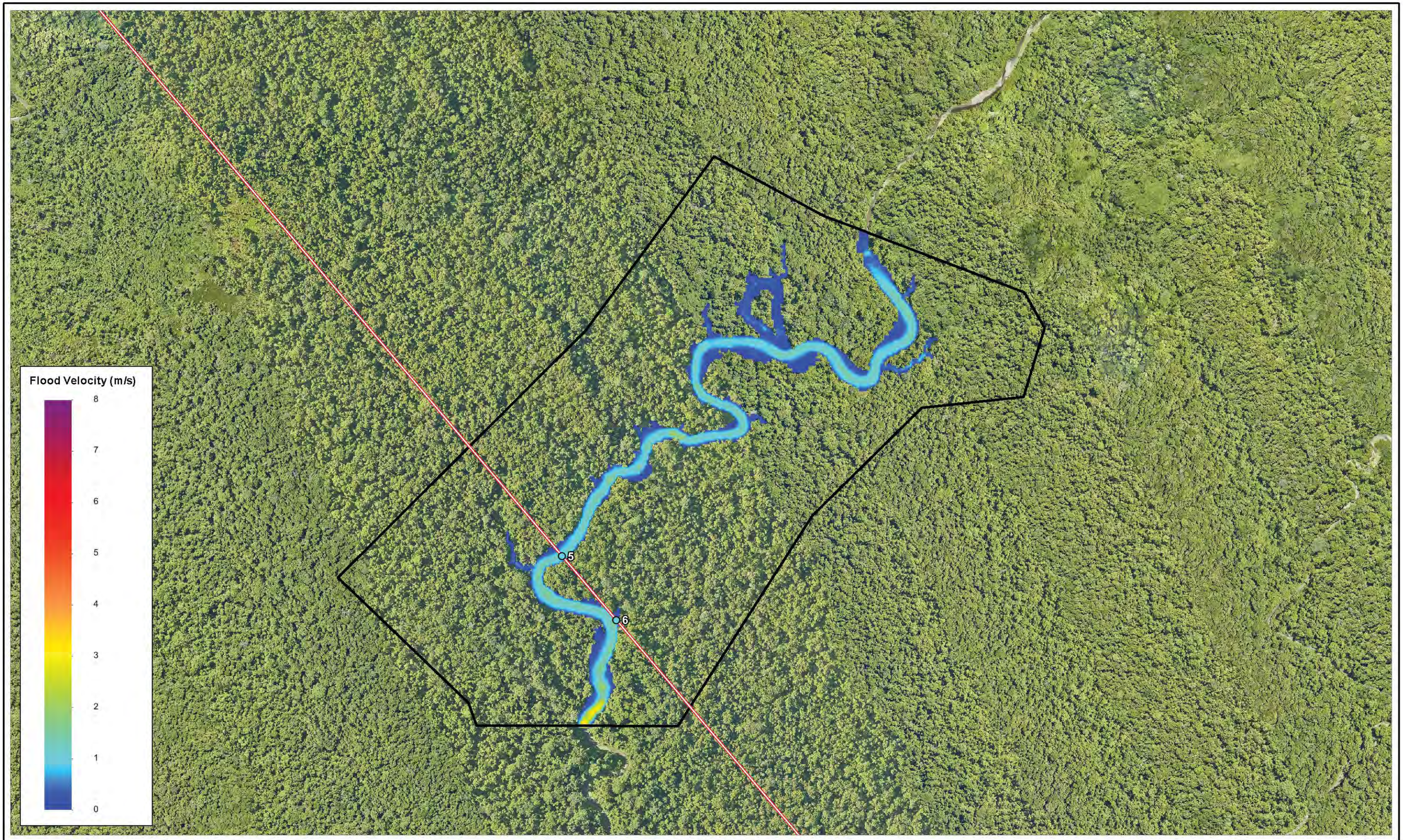
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Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S6 Flood Velocity - 100 year event

Figure: D-30

Rev: A

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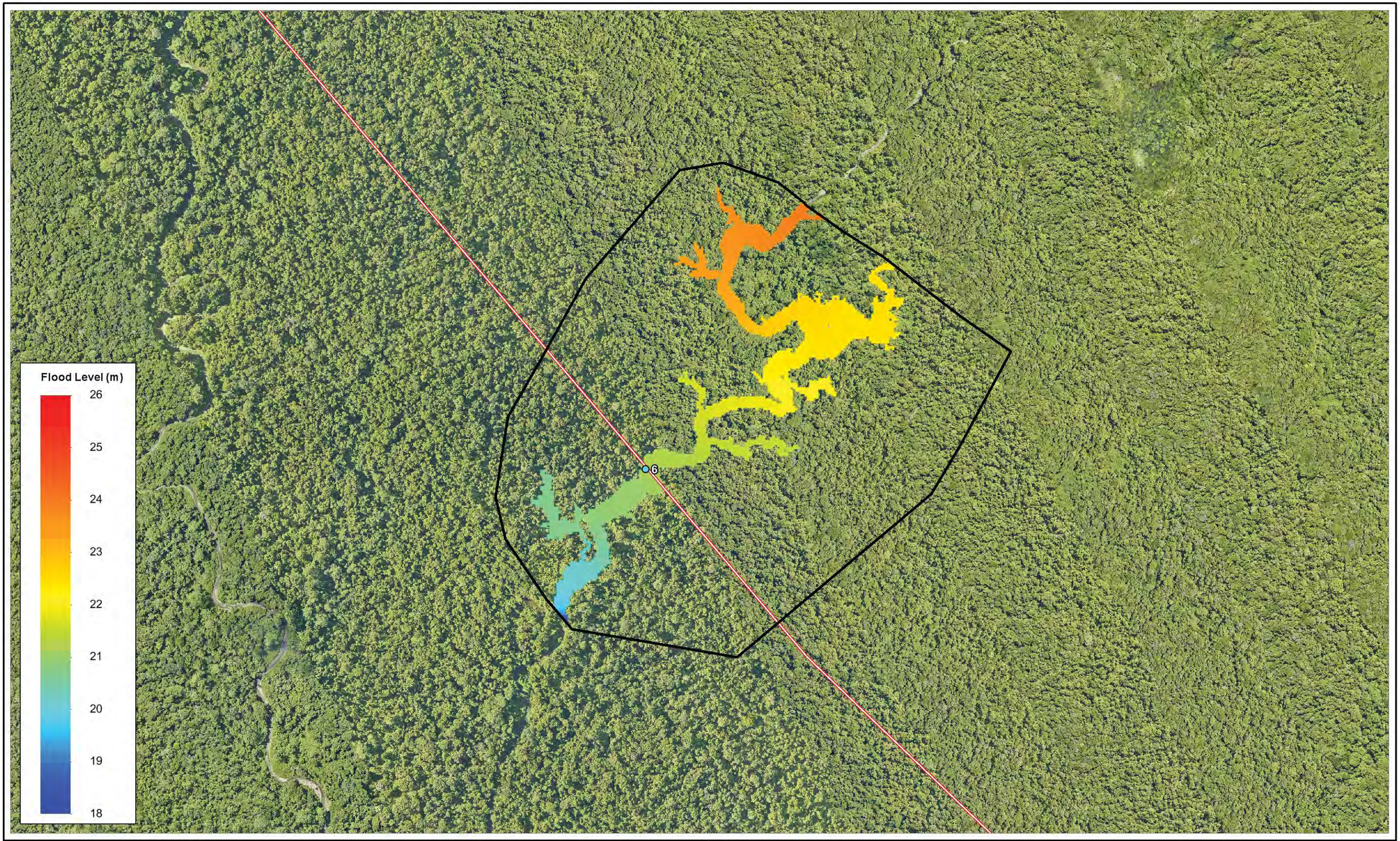
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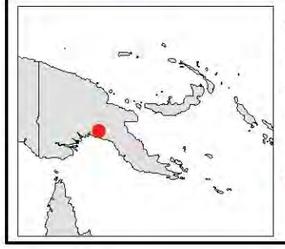
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:
Model S7 Flood Levels - 10 year event

Figure: D-31

Rev: A

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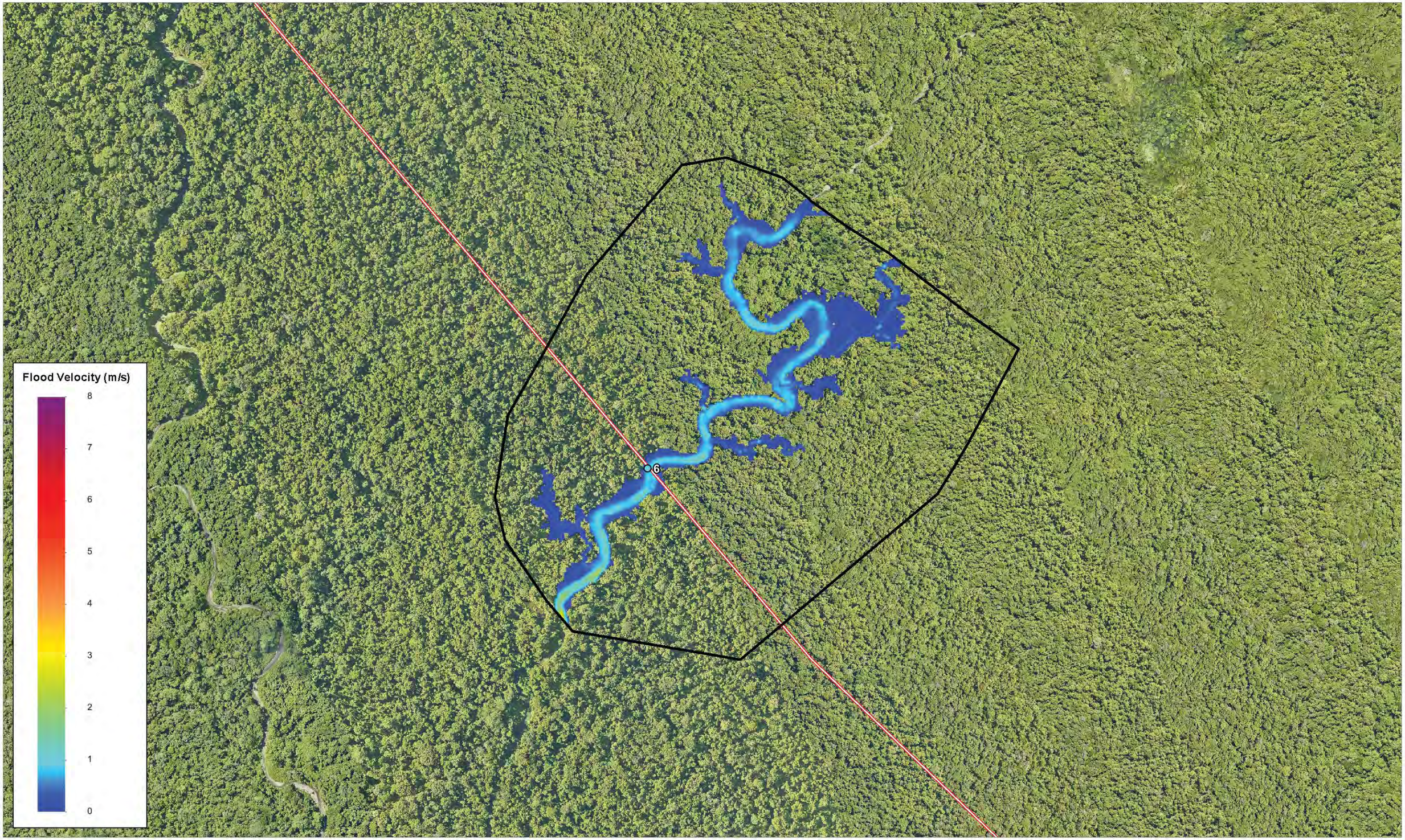
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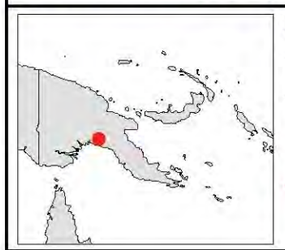
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Approx. Scale

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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:
Model S7 Flood Velocity - 10 year event

Figure: D-32

Rev: A

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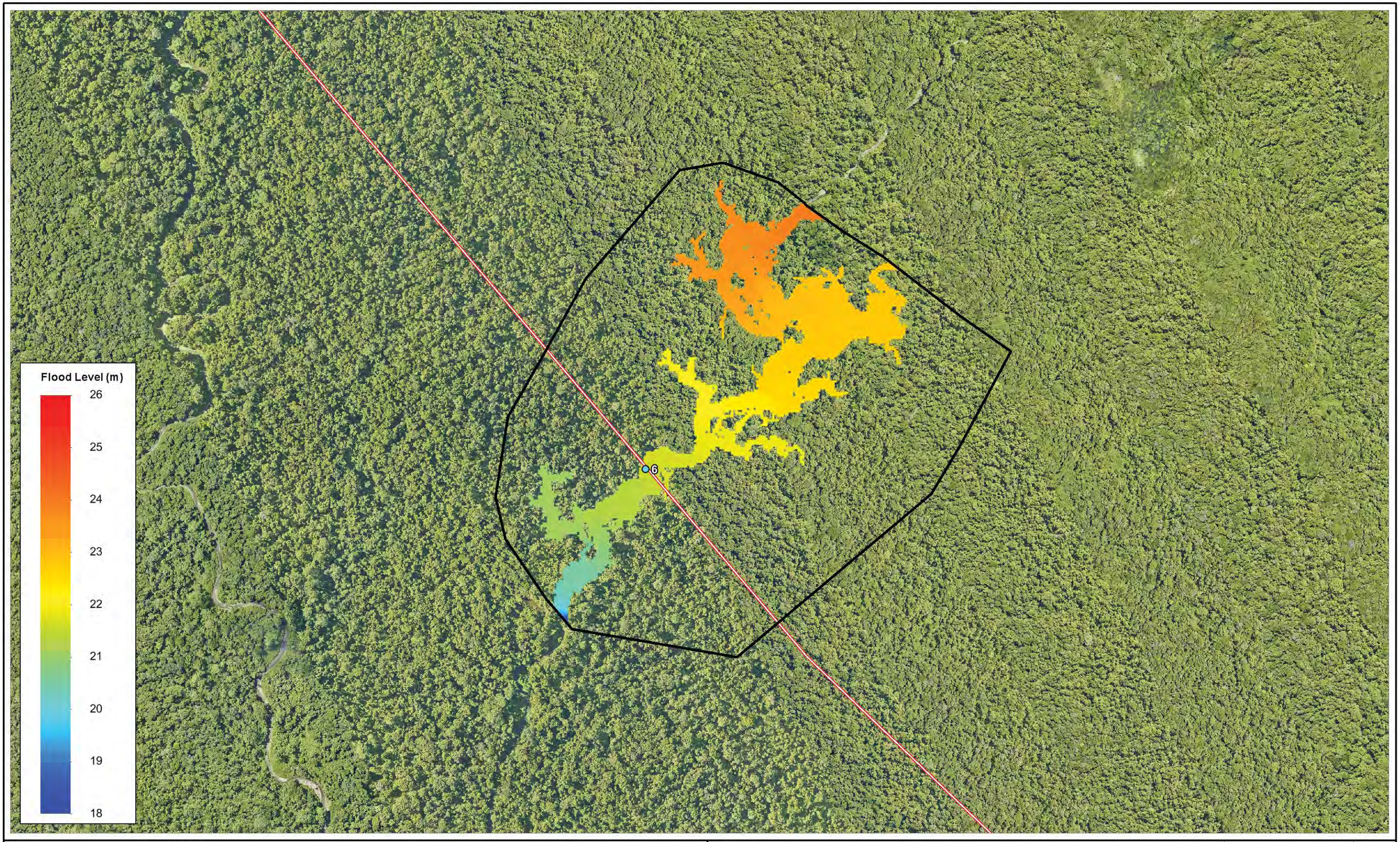
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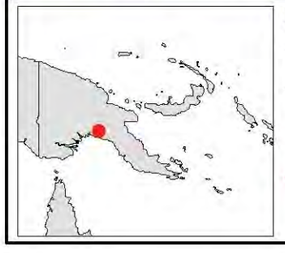
0 200 400m

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S7 Flood Levels - 50 year event

Figure: D-33

Rev: A

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N

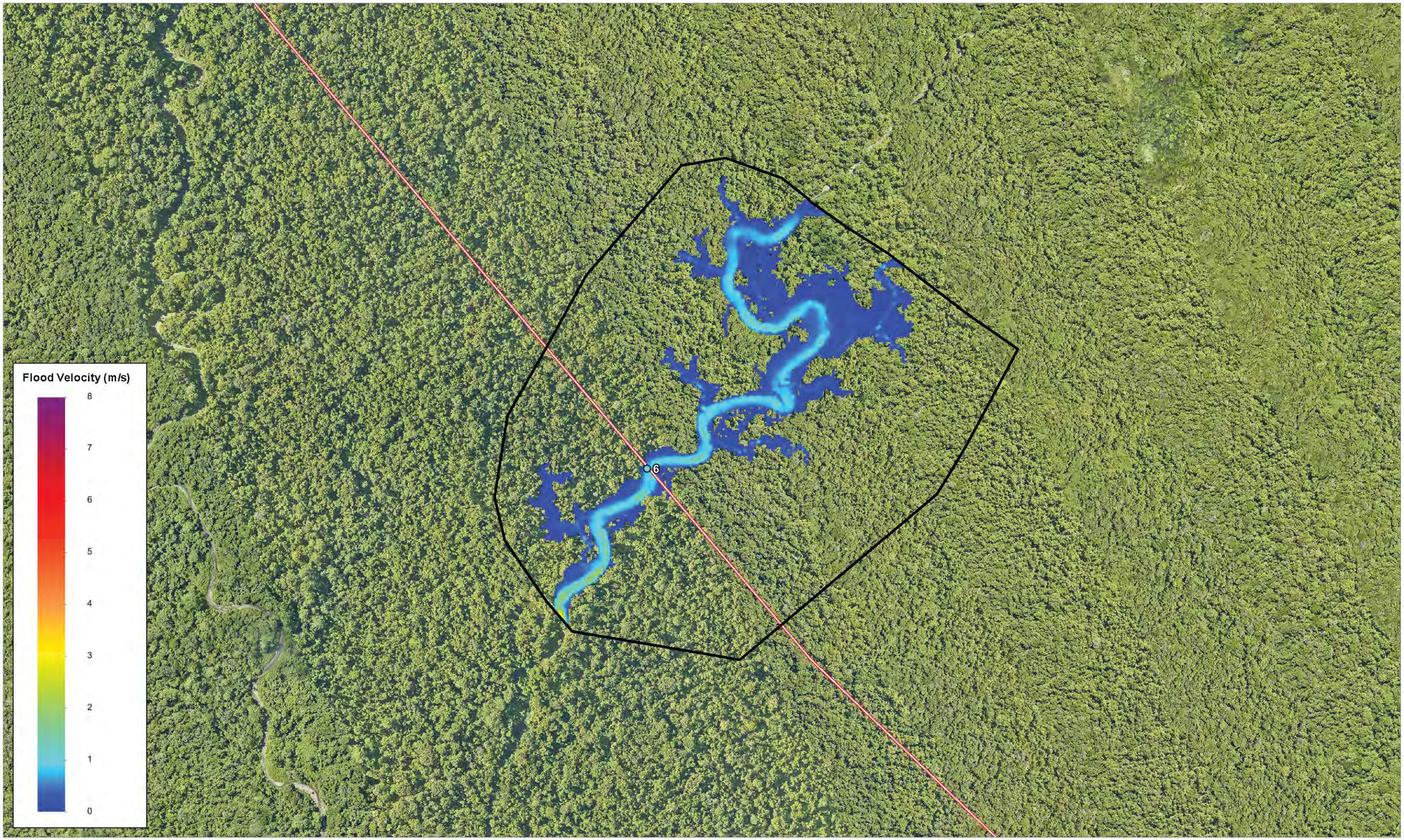
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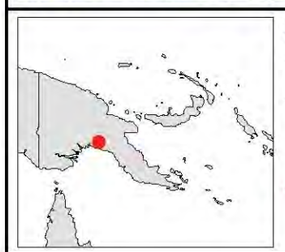
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S7 Flood Velocity - 50 year event

Figure: D-34

Rev: A

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N

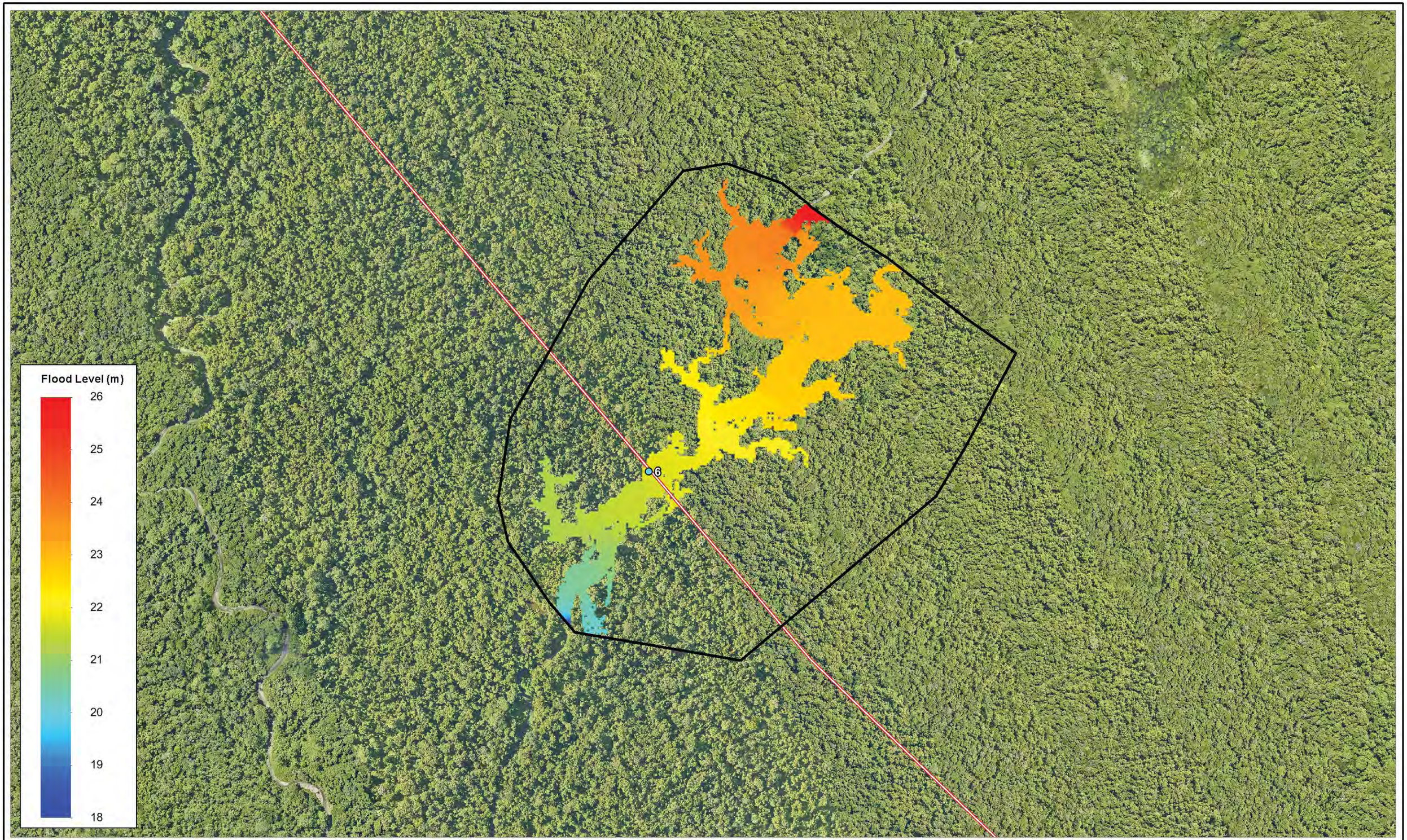
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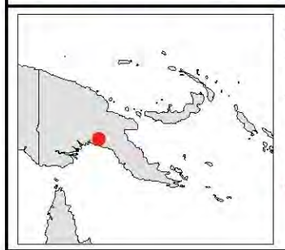
Approx. Scale

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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S7 Flood Levels - 100 year event

Figure: D-35

Rev: A

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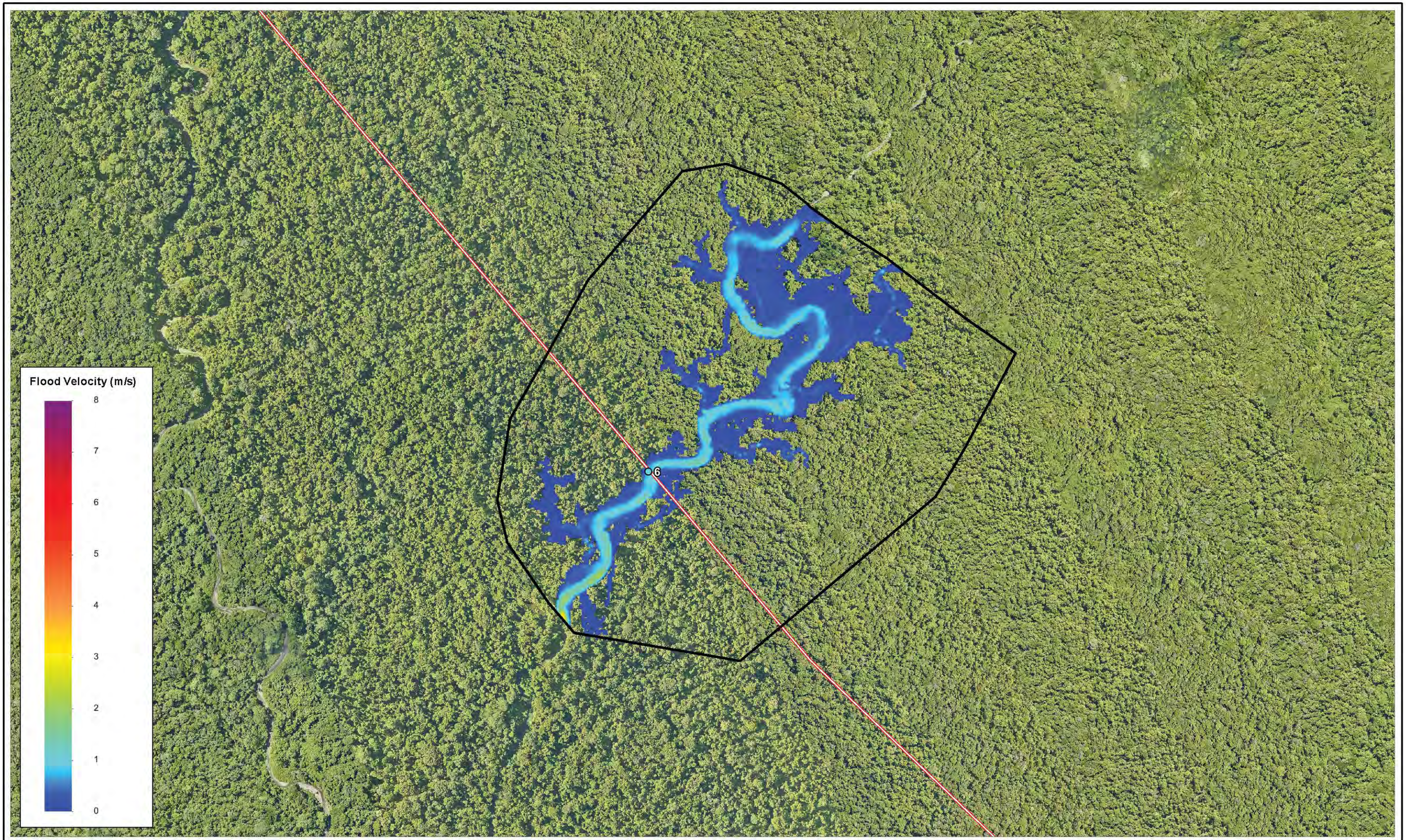
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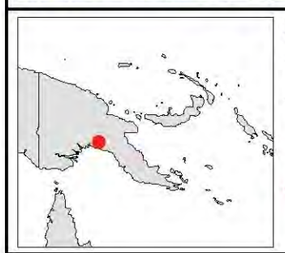
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:
Model S7 Flood Velocity - 100 year event

Figure: D-36

Rev: A

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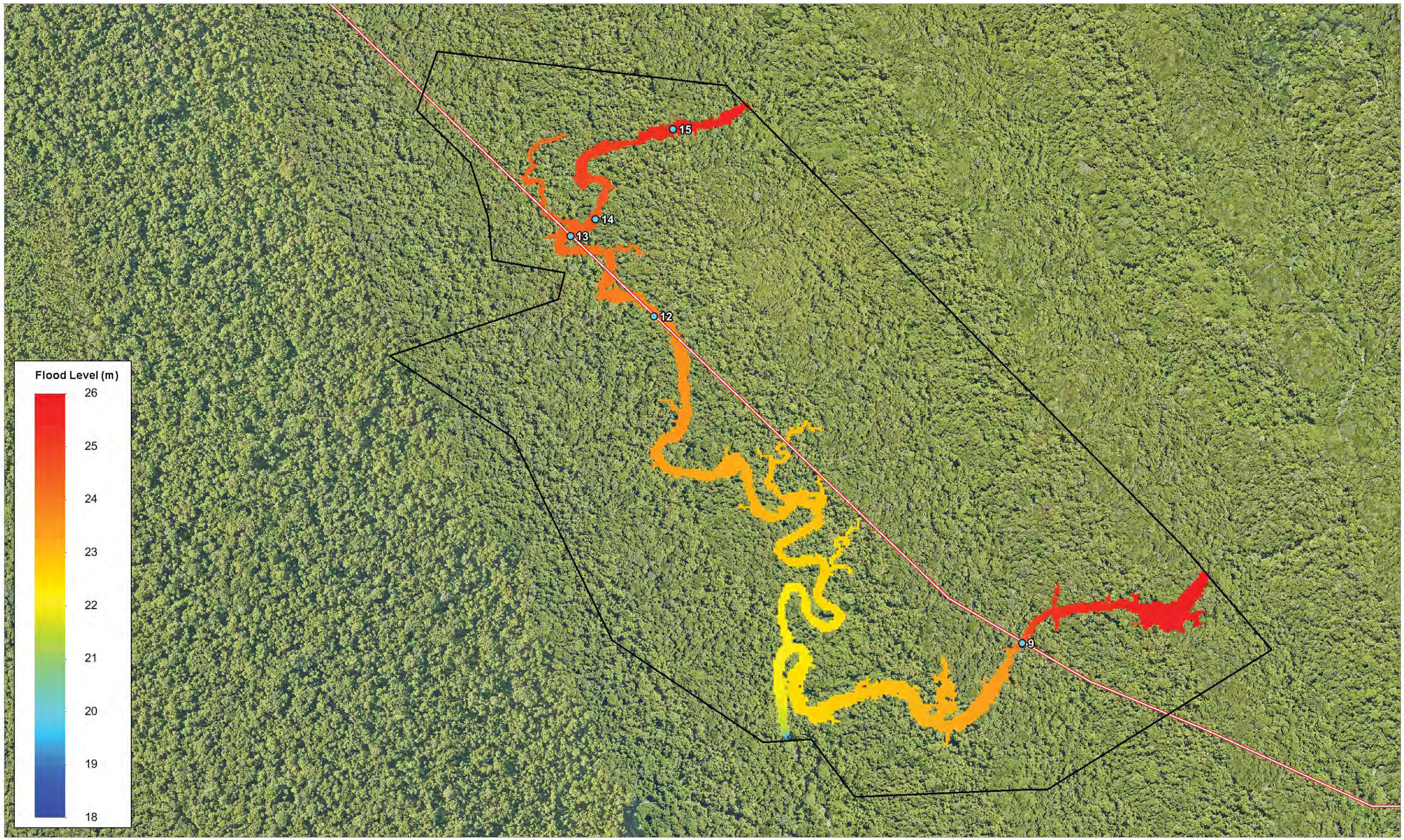
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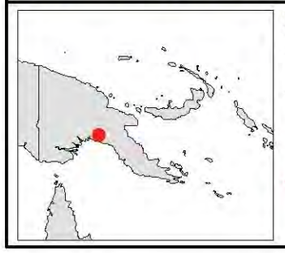
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Approx. Scale

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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S8 Flood Levels - 10 year event

Figure: D-37

Rev: A

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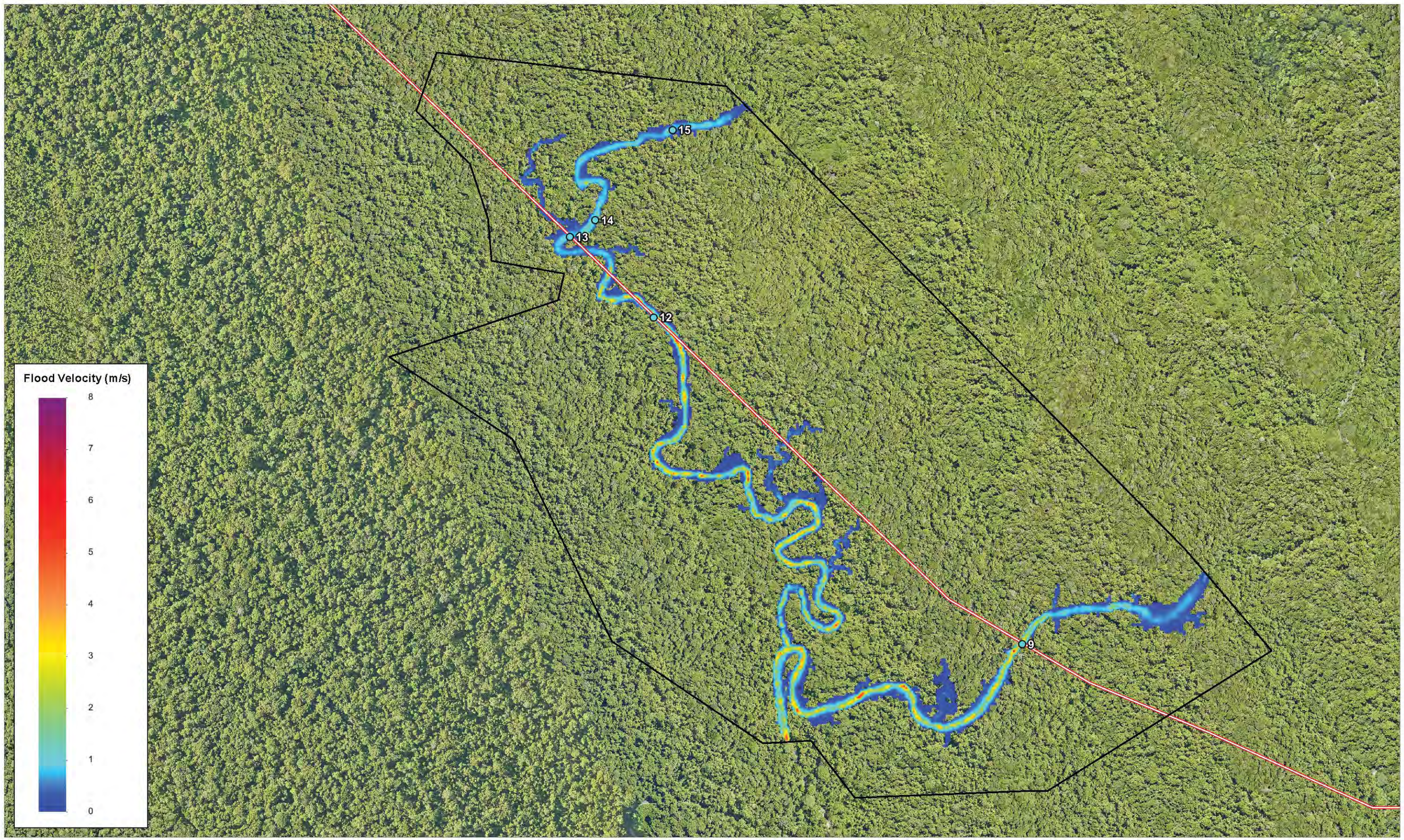
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Approx. Scale

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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S8 Flood Velocity - 10 year event

Figure: D-38

Rev: A

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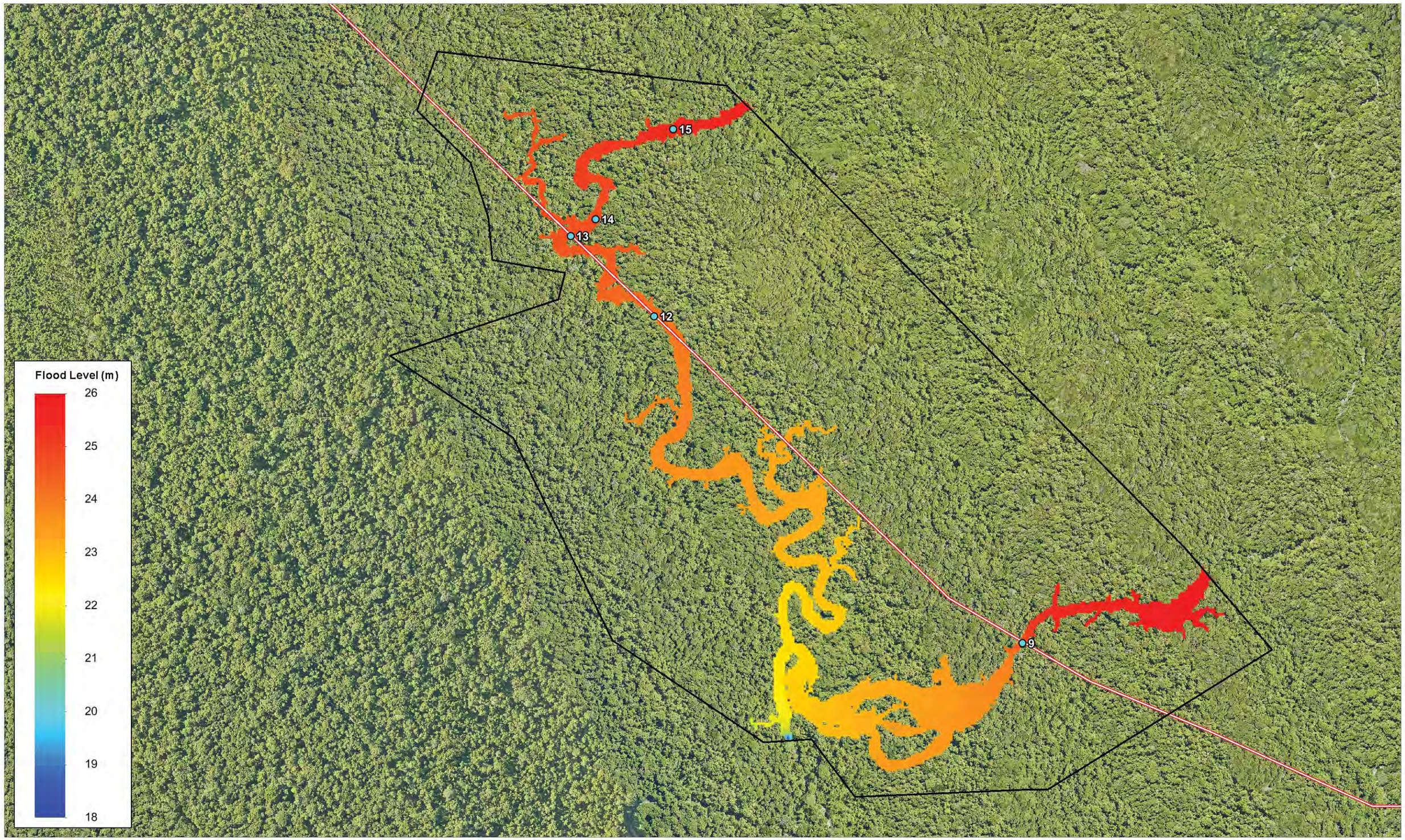
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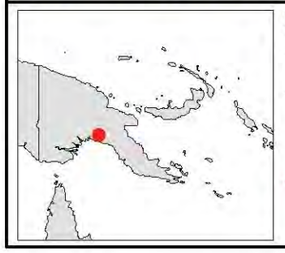
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Approx. Scale

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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S8 Flood Levels - 50 year event

Figure: D-39

Rev: A

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N

0 200 400m

Approx. Scale

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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S8 Flood Velocity - 50 year event

Figure: D-40

Rev: A

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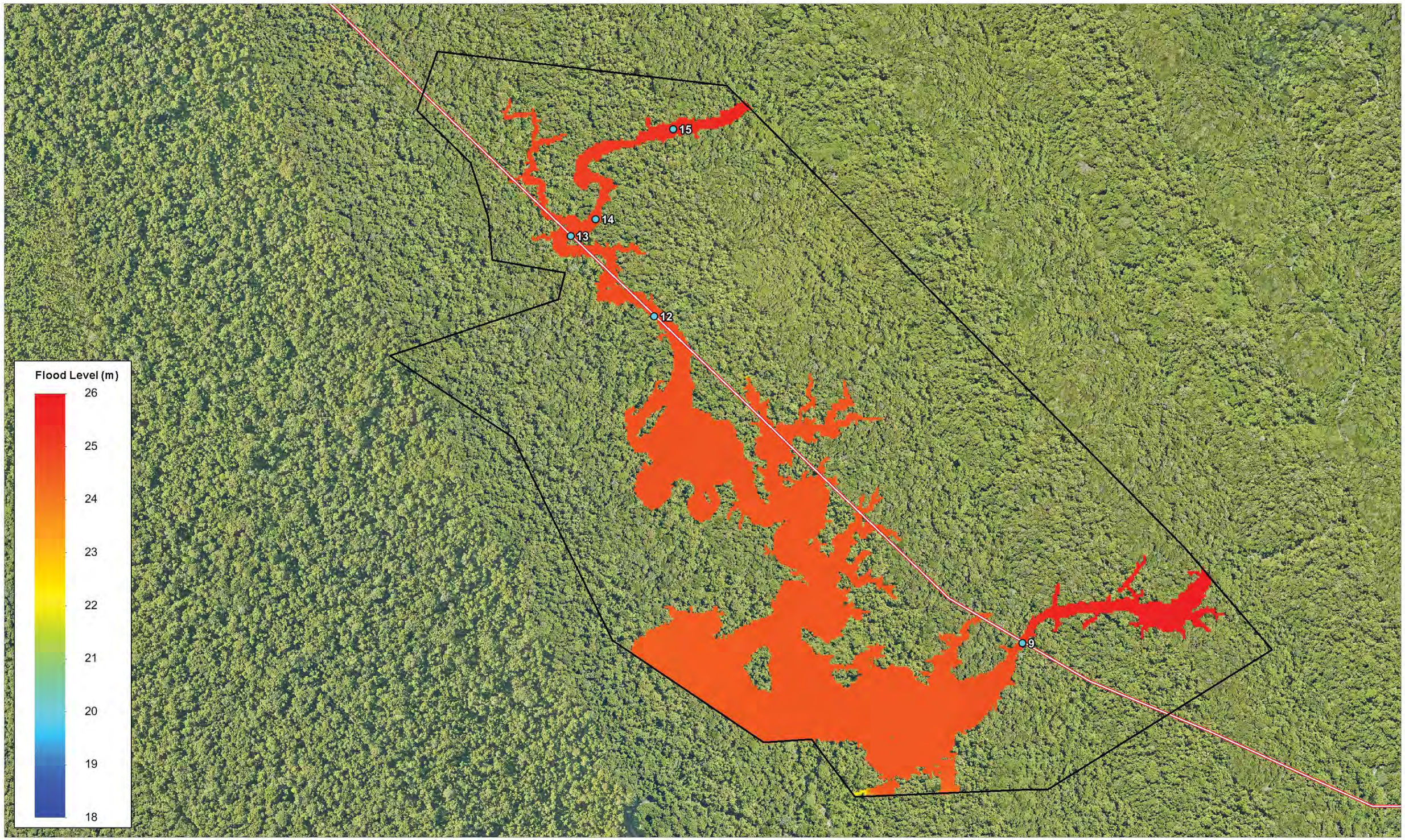
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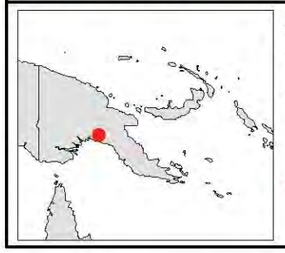
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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S8 Flood Levels - 100 year event

Figure: D-41

Rev: A

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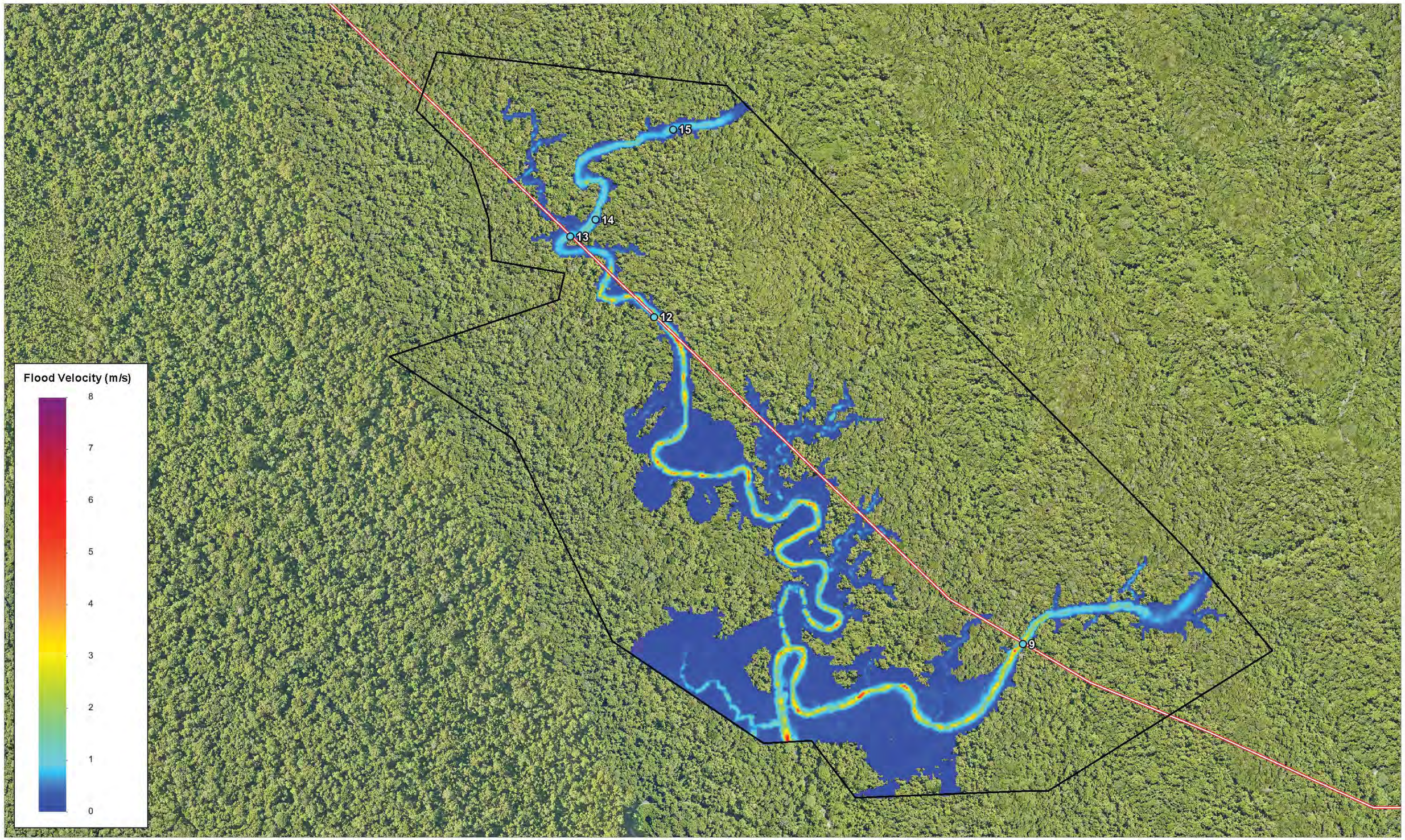
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Approx. Scale

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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S8 Flood Velocity - 100 year event

Figure: D-42

Rev: A

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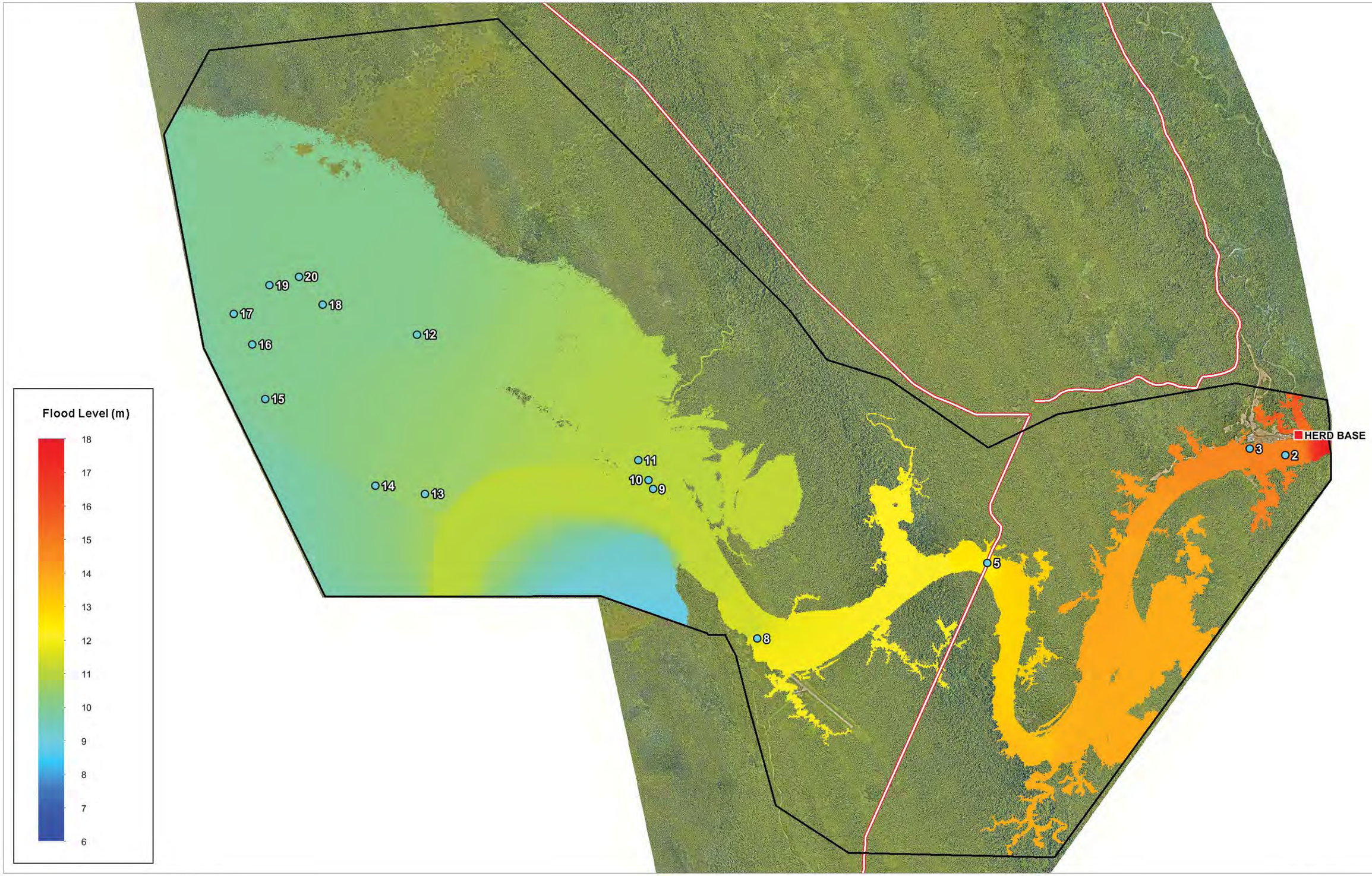
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0 200 400m

Approx. Scale

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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_048_170317_S8_v_100y.wor



LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option
- Herd Base

Title:

Model S10 Flood Levels - 10 year event

Figure: D-43

Rev: A

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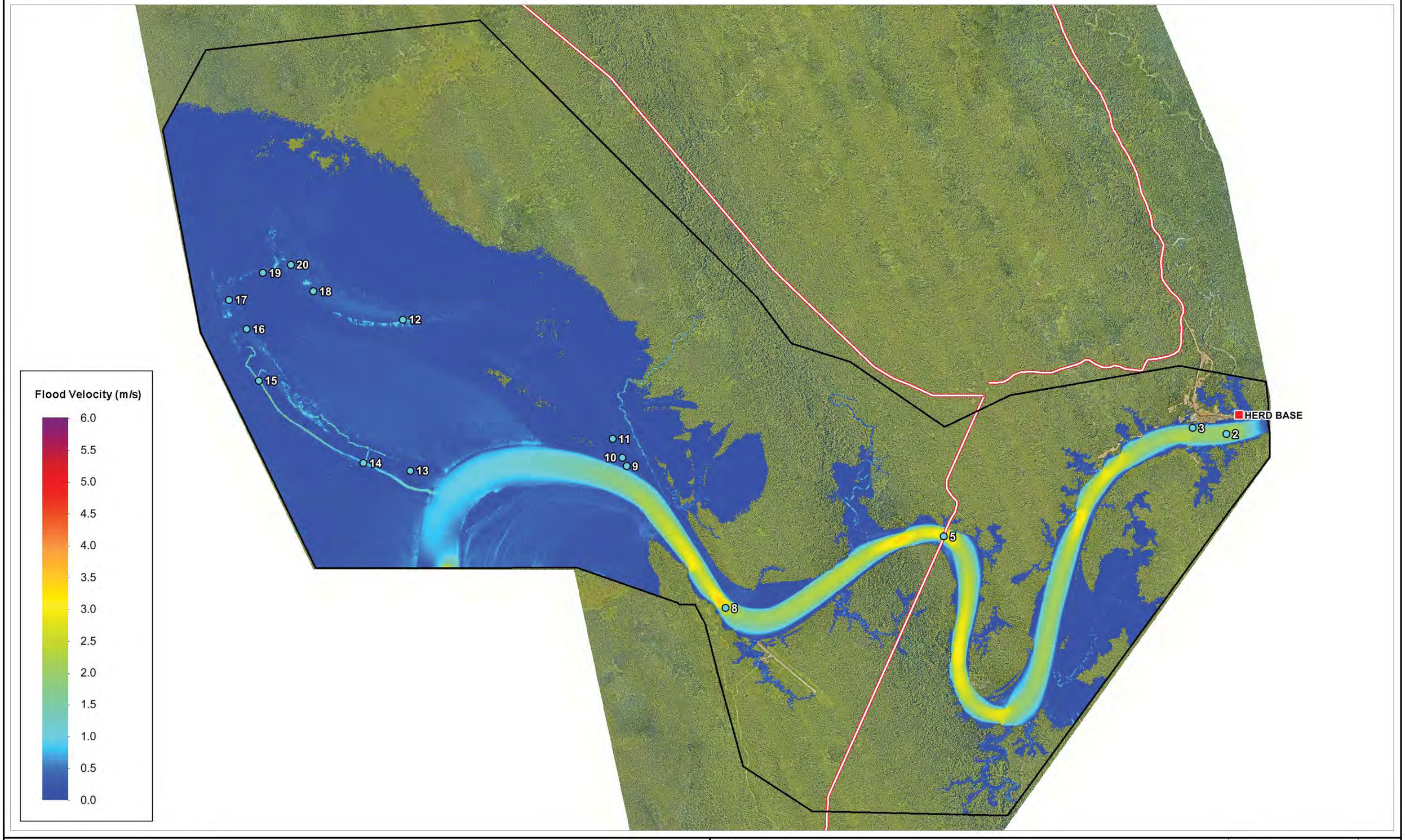
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Approx. Scale

BMT WBM

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option
- Herd Base

Title:

Model S10 Flood Velocity - 10 year event

Figure: D-44

Rev: A

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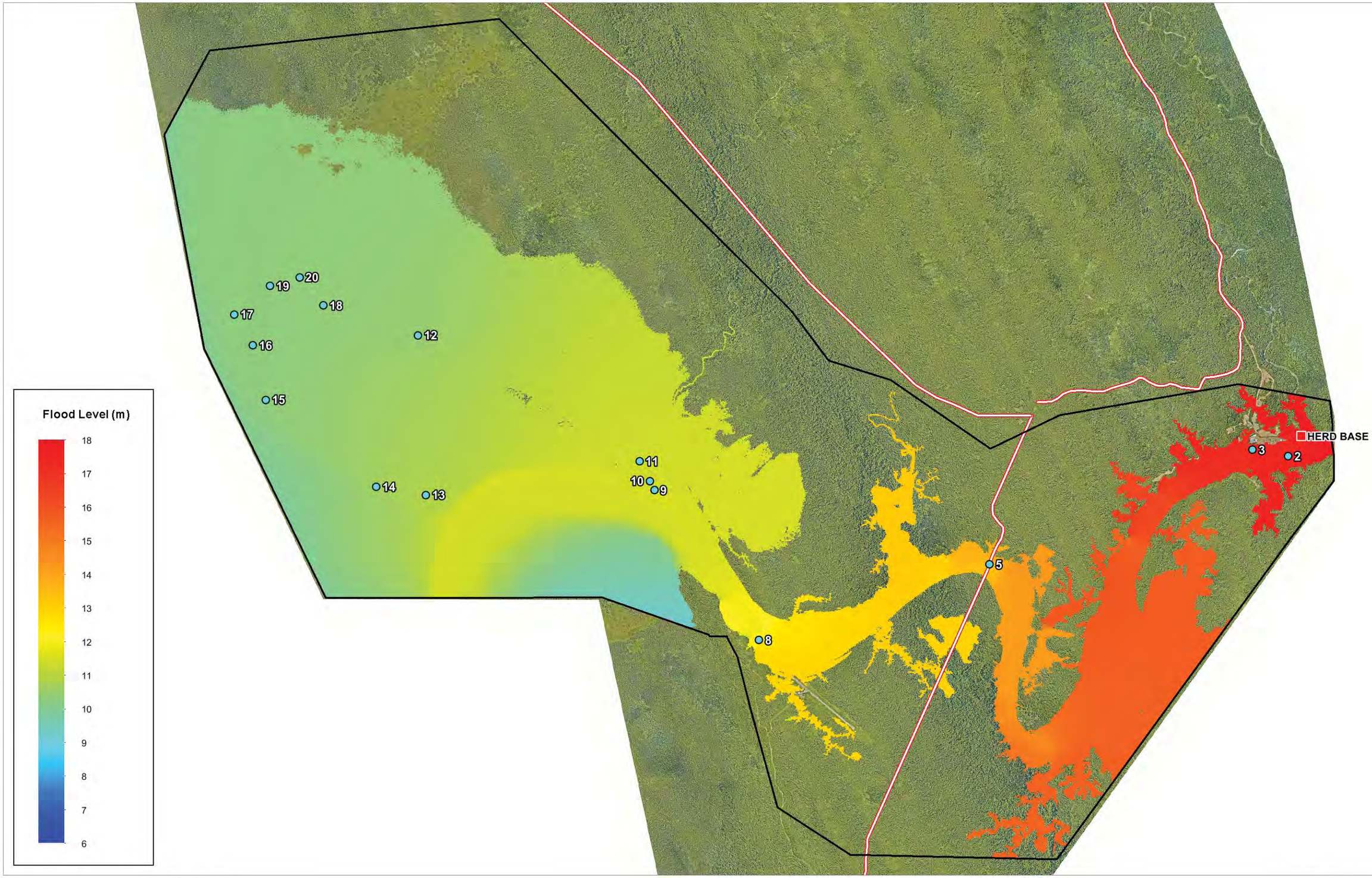
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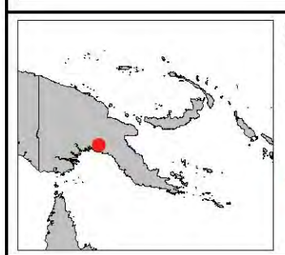
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Approx. Scale

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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_050_170317_S10_v_10y.wor





LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option
- Herd Base

Title:

Model S10 Flood Levels - 50 year event

Figure: D-45

Rev: A

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0 1 2km

Approx. Scale

BMT WBM

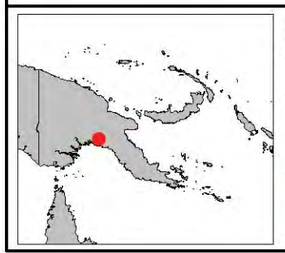
www.bmtwbm.com.au

Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_051_170317_S10_h_50y.wor

Flood Velocity (m/s)

6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0

20 19 18 17 16 12 15 14 13 11 10 9 8 5 3 2 HERD BASE



LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option
- Herd Base

Title:
Model S10 Flood Velocity - 50 year event

Figure: D-46

Rev: A

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N

0 1 2km
Approx. Scale

BMT WBM
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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_052_170317_S10_v_50y.wor

Flood Level (m)

18
17
16
15
14
13
12
11
10
9
8
7
6

20
19
18
17
16
12
15
14
13
11
10
9
8
5
3
2
HERD BASE

LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Herd Base

Title:

Model S10 Flood Levels - 100 year event

Figure: D-47

Rev: A

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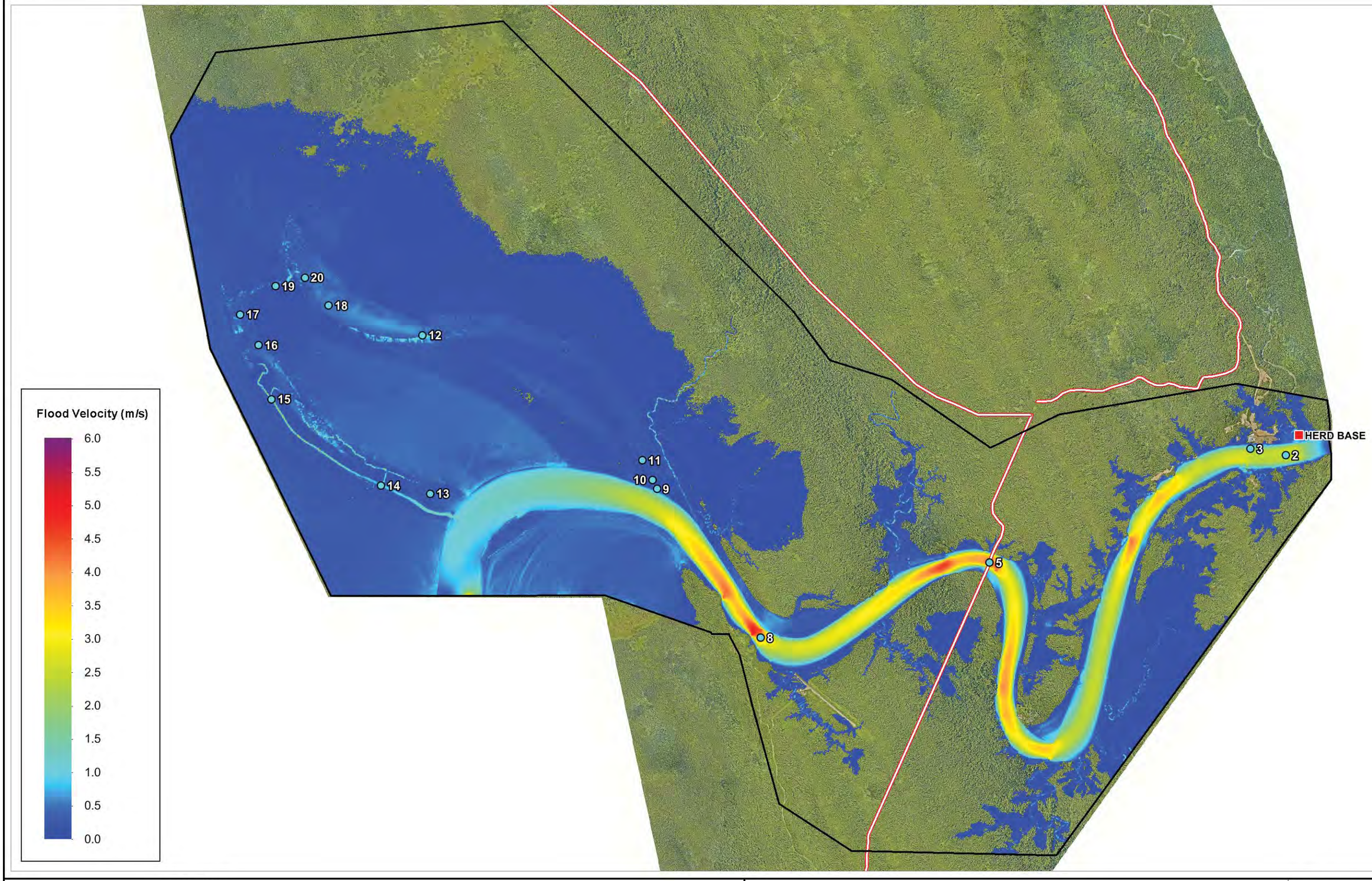
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0 1 2km

Approx. Scale

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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_053_170317_S10_h_100y.wor



LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option
- Herd Base

Title:

Model S10 Flood Velocity - 100 year event

Figure: D-48

Rev: A

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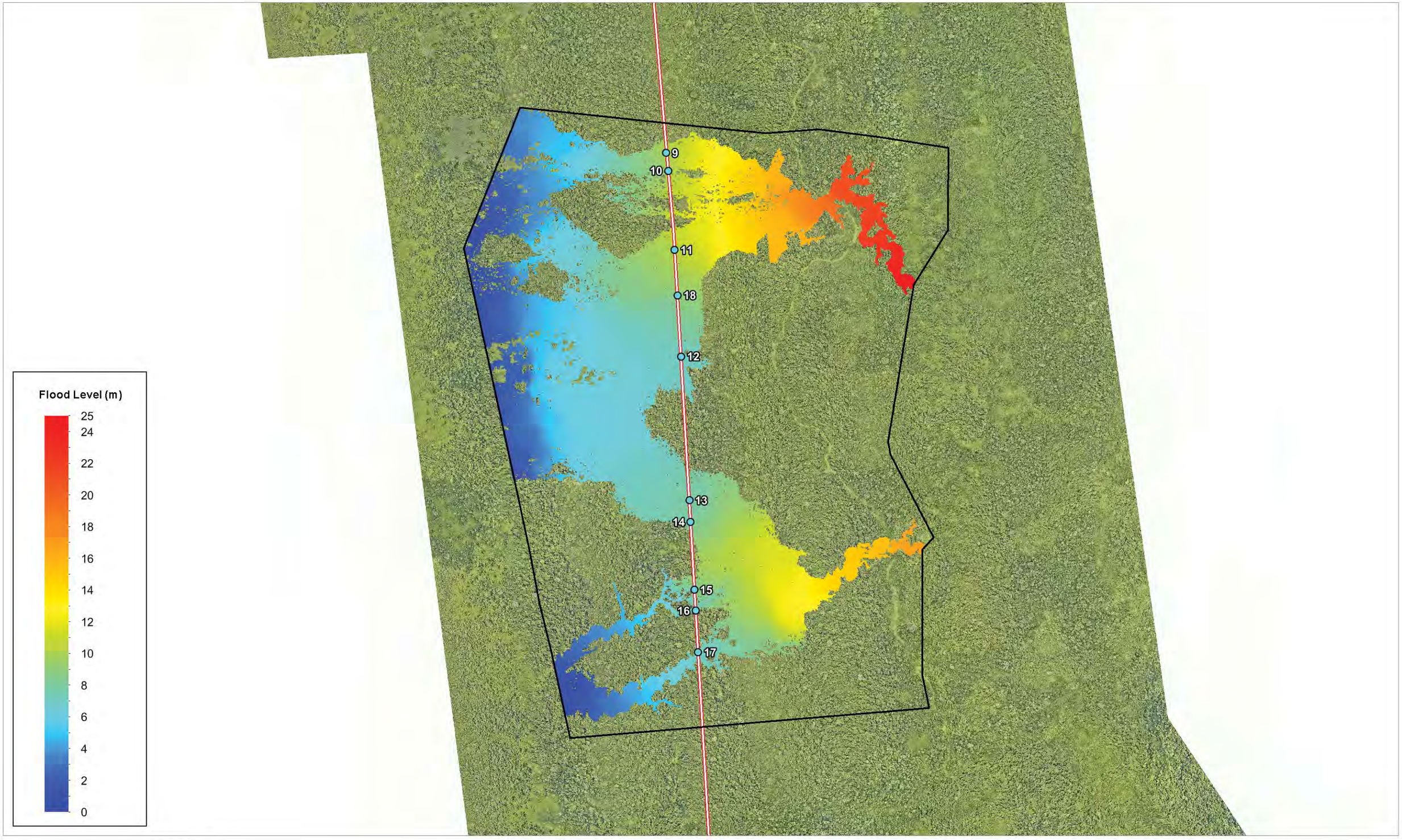
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Approx. Scale

BMT WBM

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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_054_170317_S10_v_100y.wor





LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S11 Flood Levels - 10 year event

Figure: D-49

Rev: A

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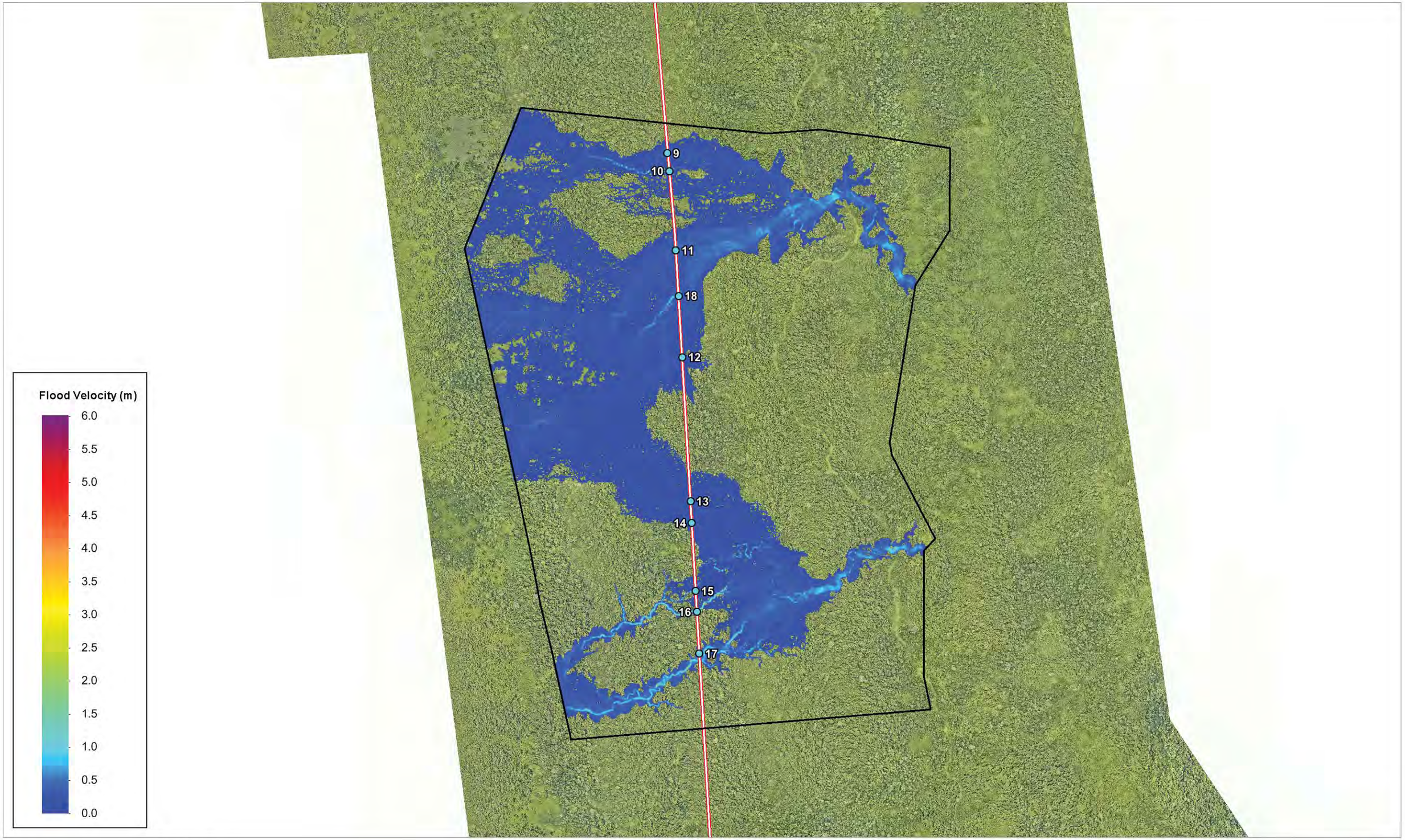
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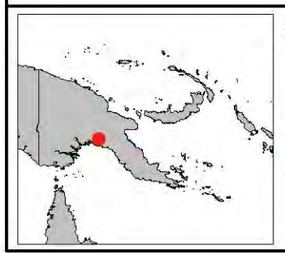
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:
Model S11 Flood Velocity - 10 year event

Figure: D-50

Rev: A

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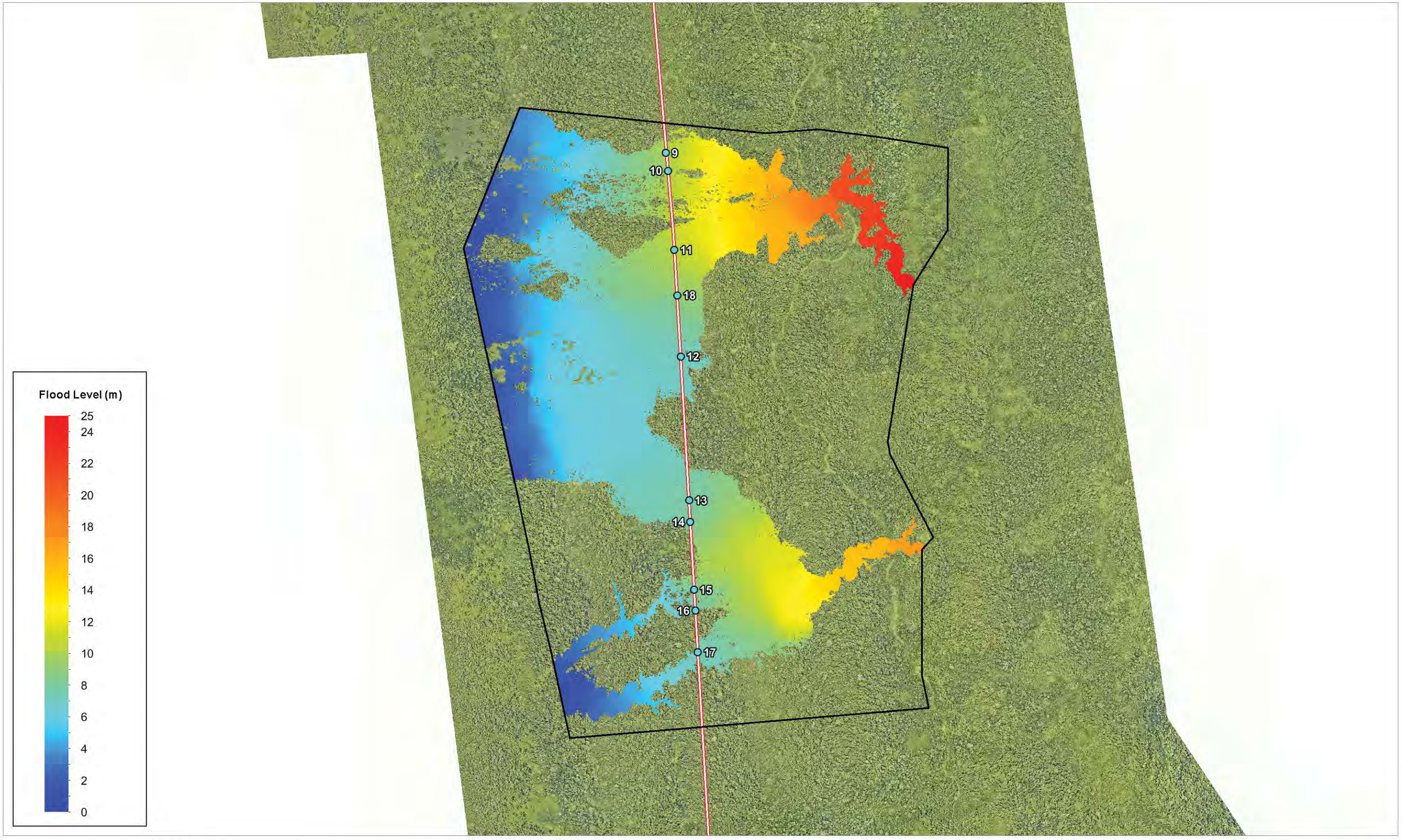
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0 500 1,000m

Approx. Scale

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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_056_170317_S11_v_10y.wor





LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S11 Flood Levels - 50 year event

Figure: D-51

Rev: A

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N

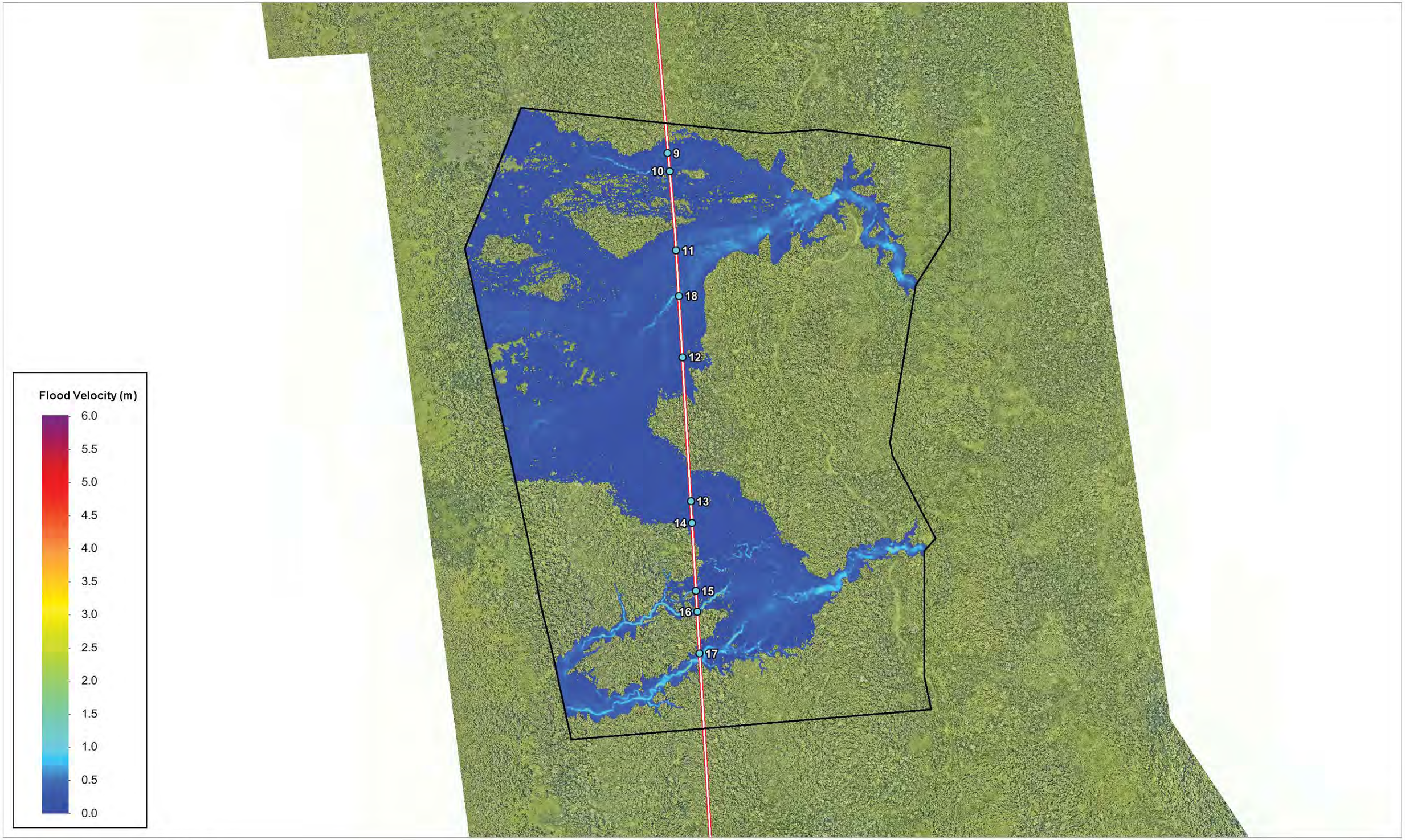
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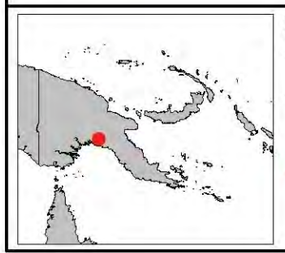
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S11 Flood Velocity - 50 year event

Figure: D-52

Rev: A

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N

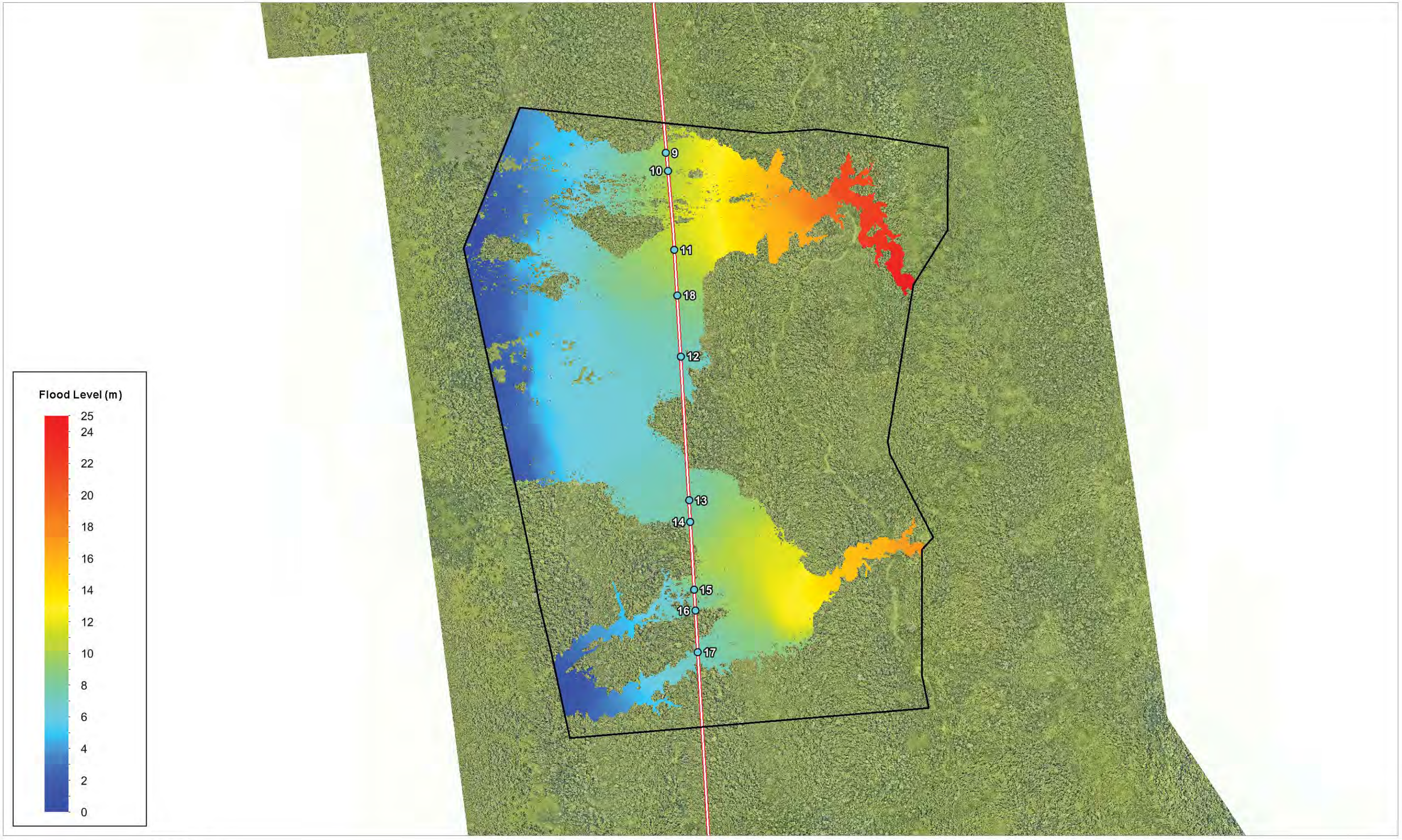
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Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S11 Flood Levels - 100 year event

Figure: D-53

Rev: A

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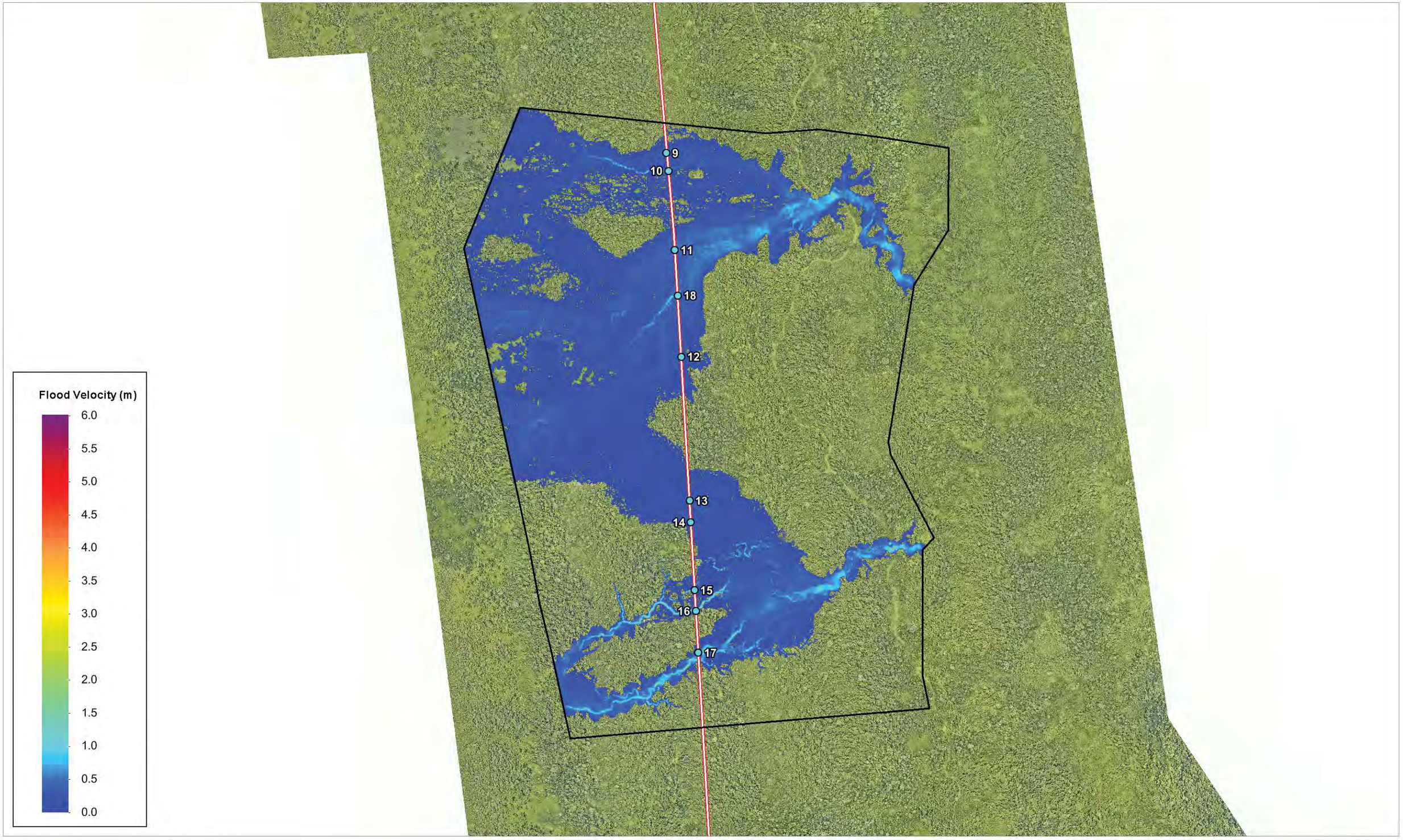
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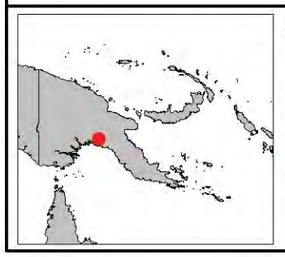
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S11 Flood Velocity - 100 year event

Figure: D-54

Rev: A

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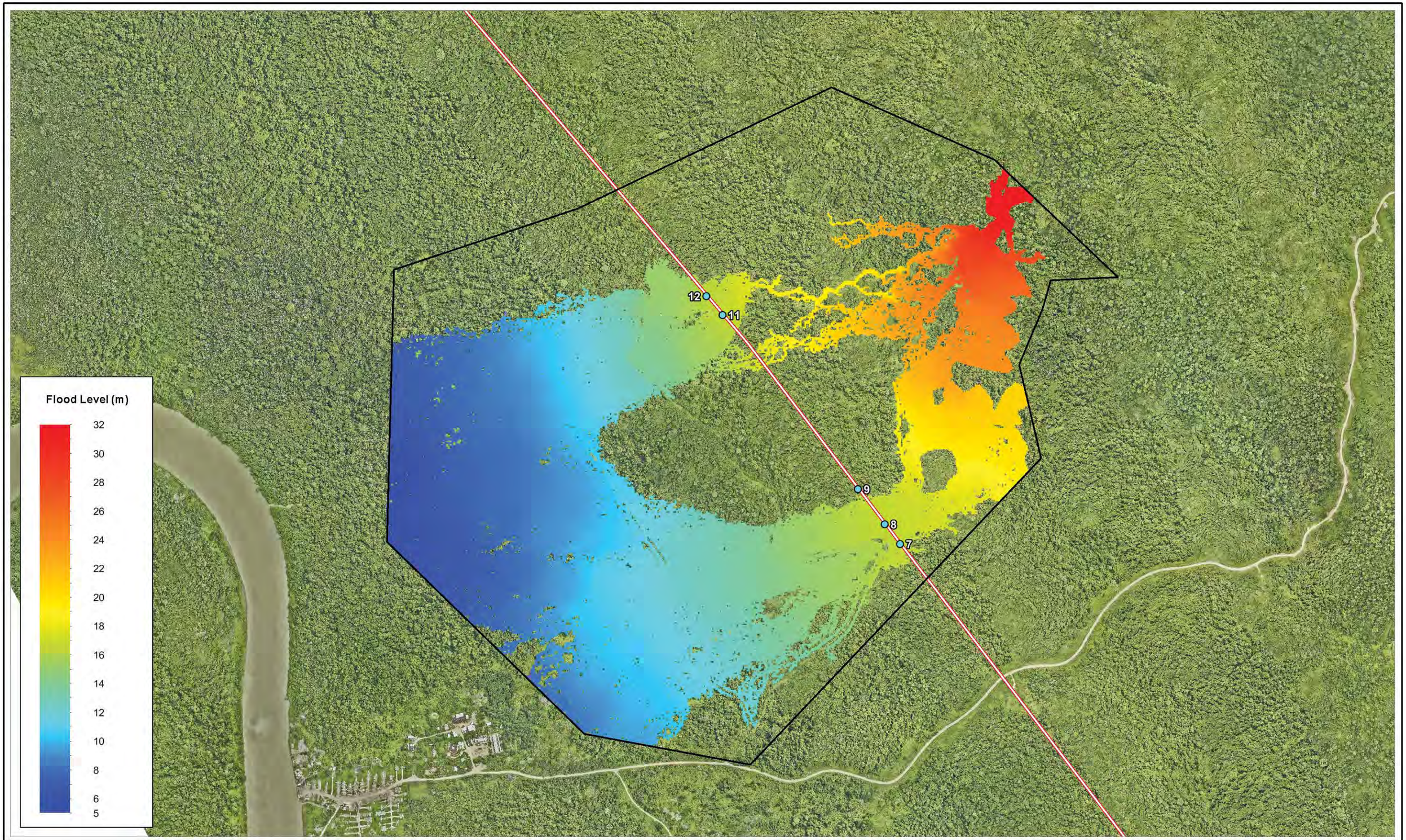
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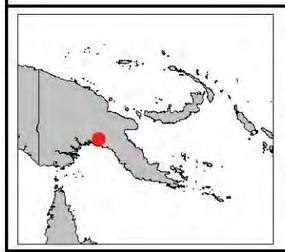
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S12 Flood Levels - 10 year event

Figure: D-55

Rev: A

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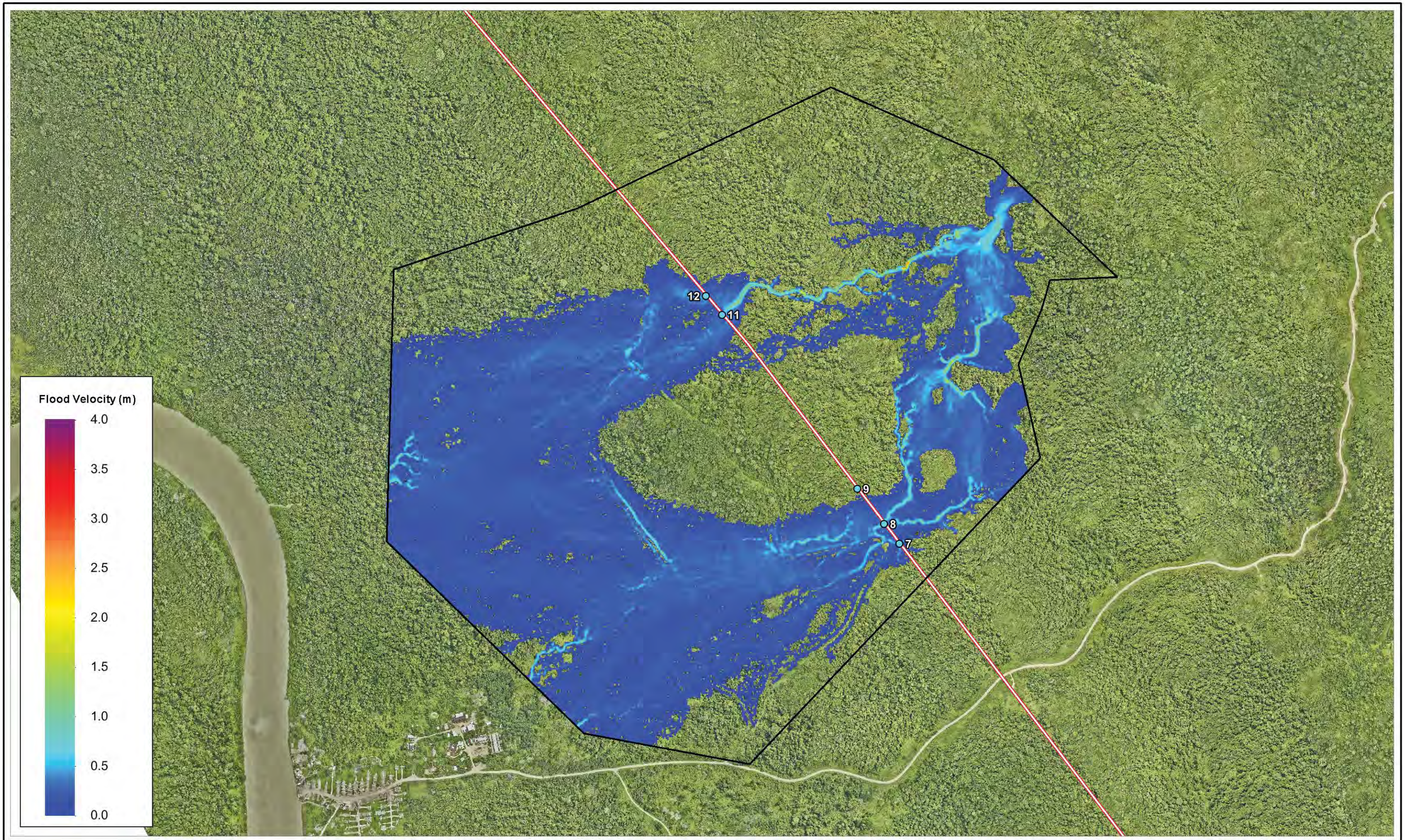
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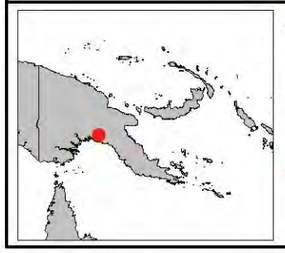
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S12 Flood Velocity - 10 year event

Figure: D-56

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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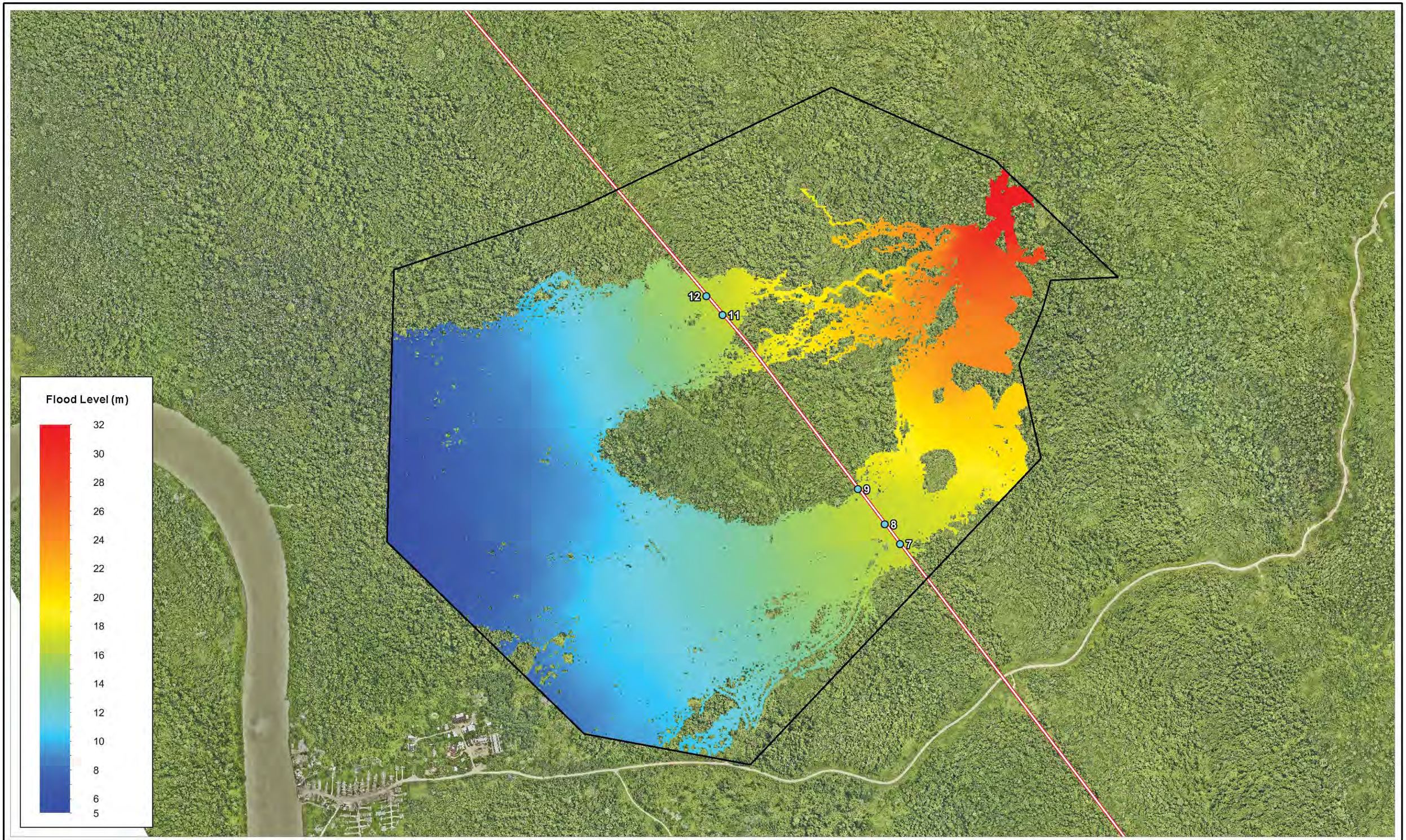
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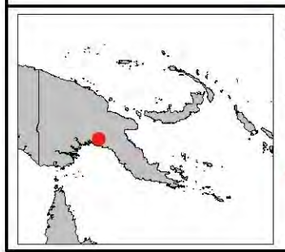
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S12 Flood Levels - 50 year event

Figure: D-57

Rev: A

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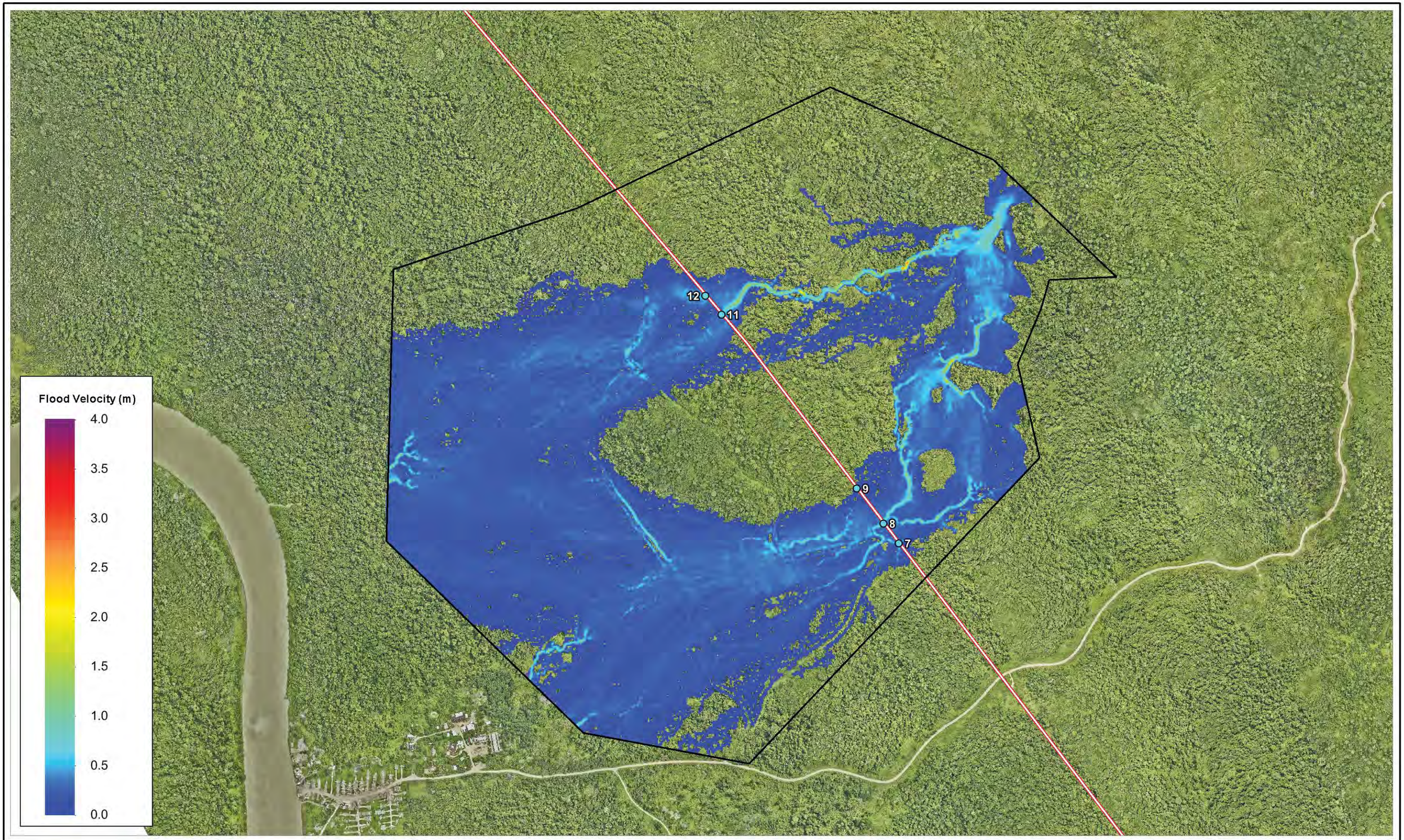
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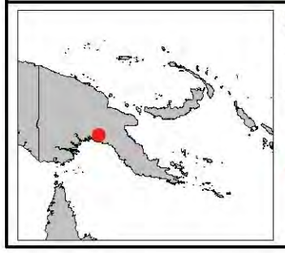
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S12 Flood Velocity - 50 year event

Figure: D-58

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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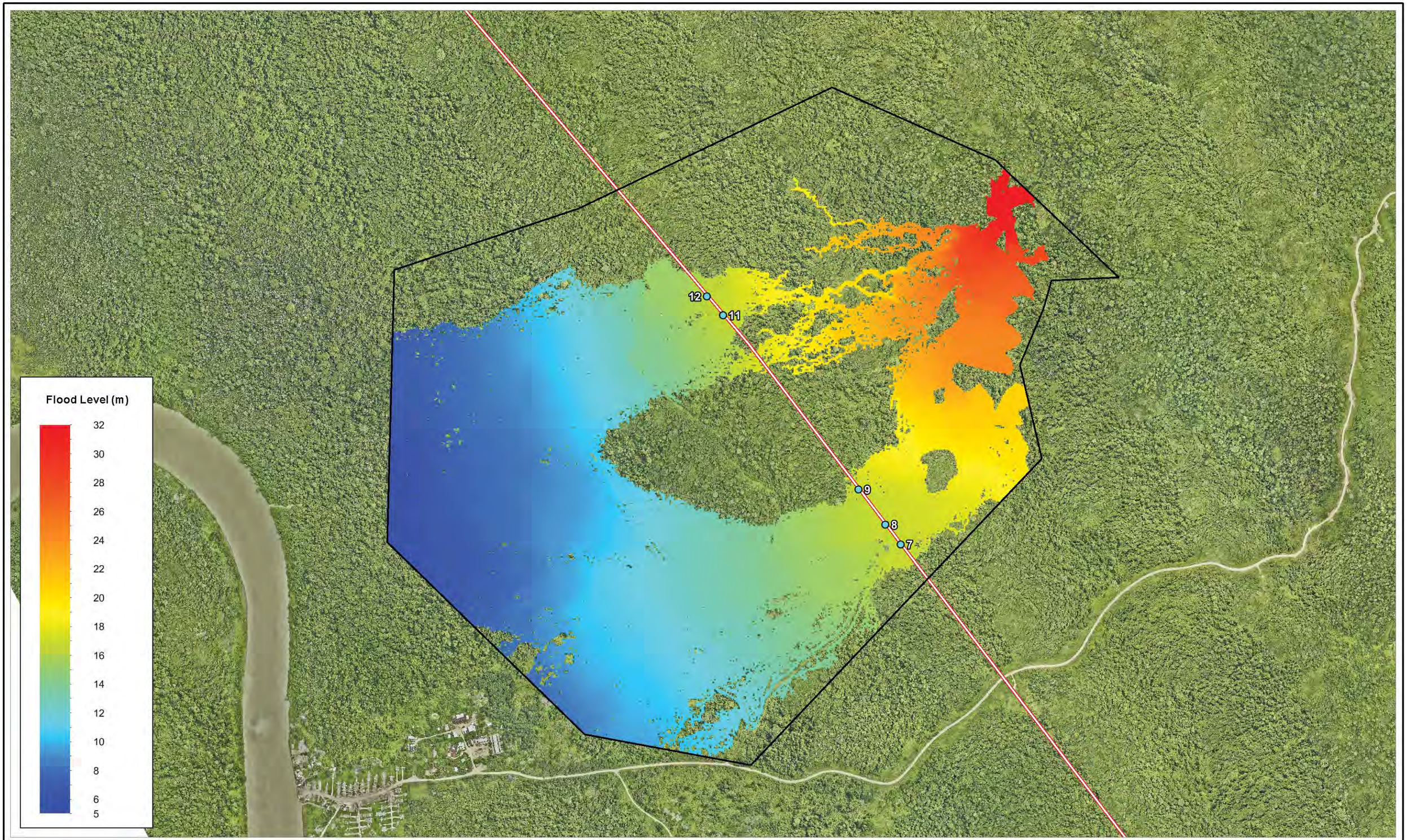
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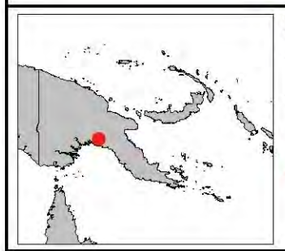
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S12 Flood Levels - 100 year event

Figure: D-59

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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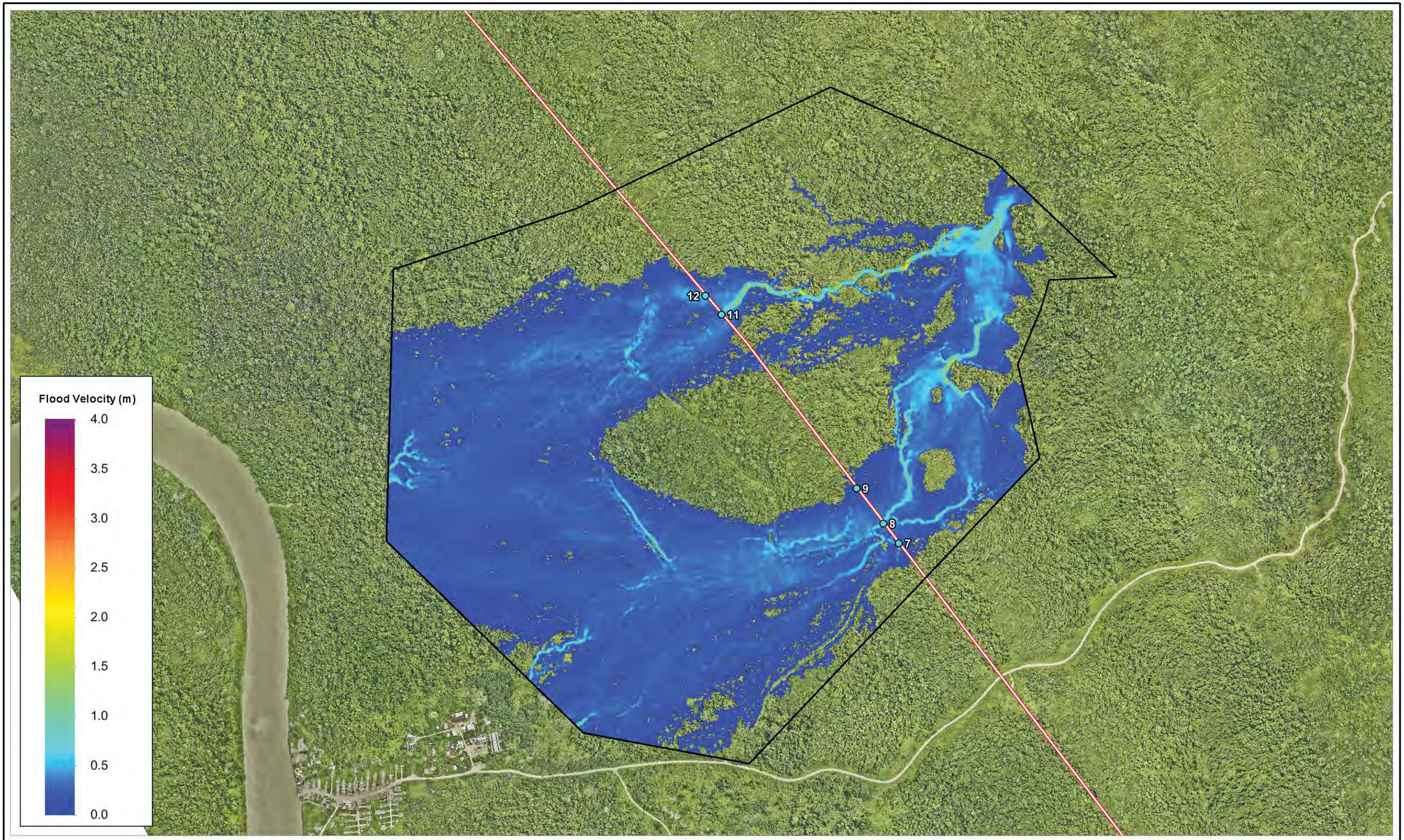
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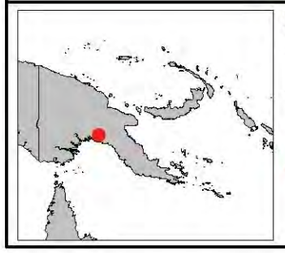
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S12 Flood Velocity - 100 year event

Figure: D-60

Rev: A

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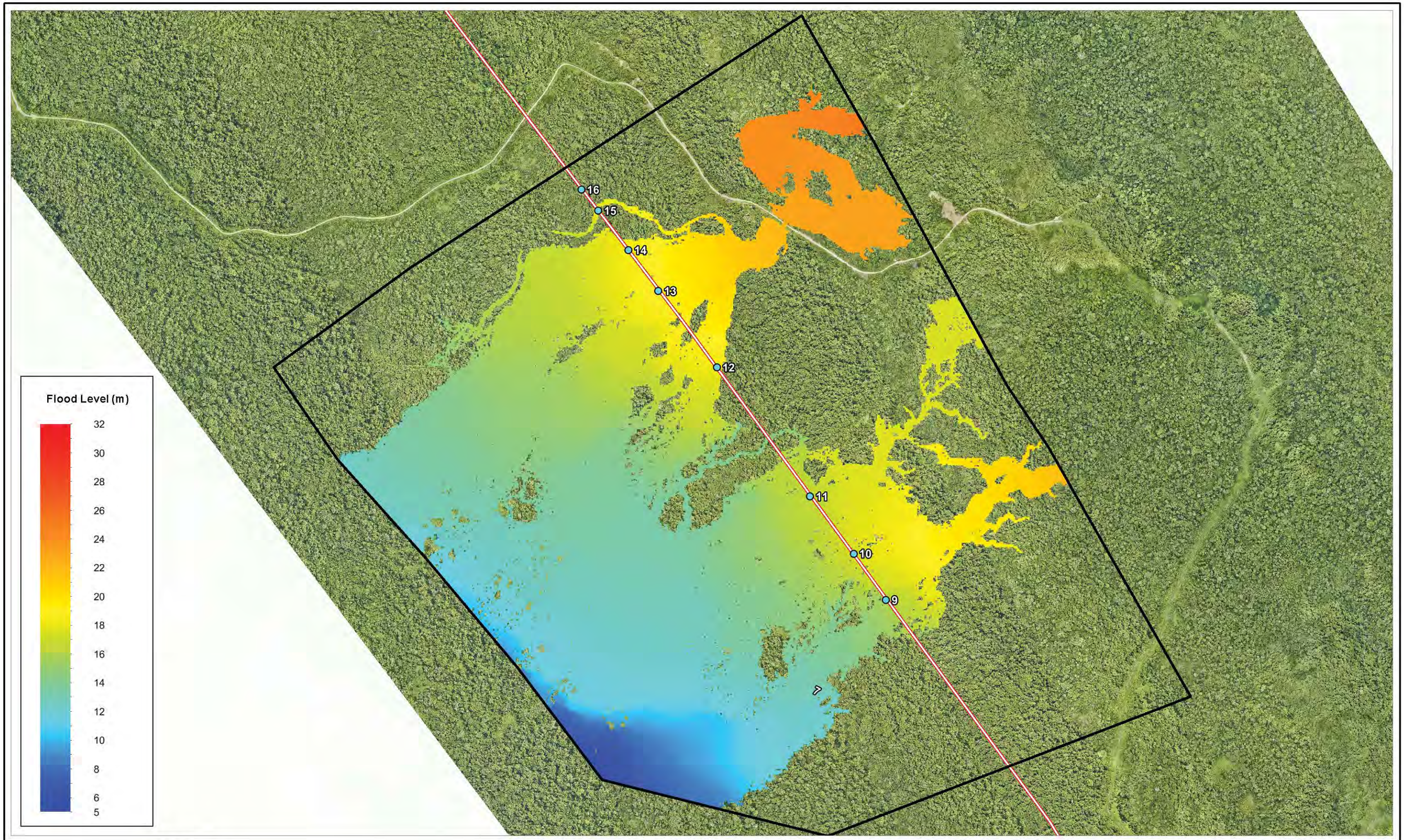
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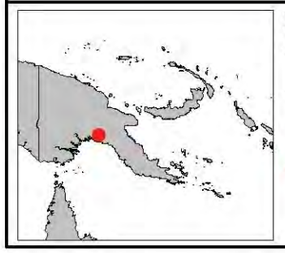
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S13 Flood Levels - 10 year event

Figure: D-61

Rev: A

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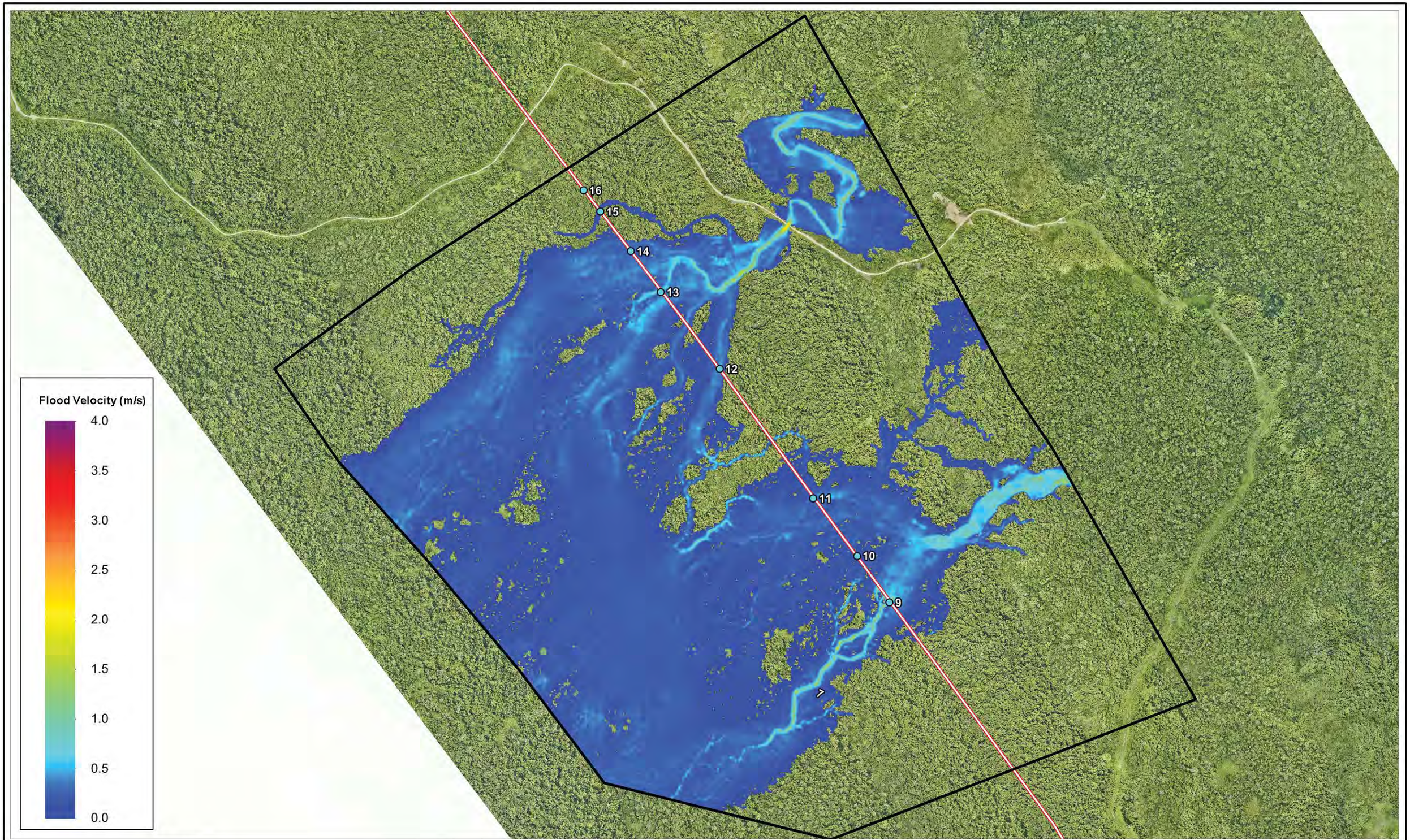
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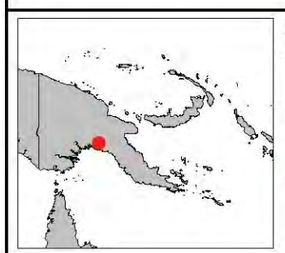
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:
Model S13 Flood Velocity - 10 year event

Figure: D-62

Rev: A

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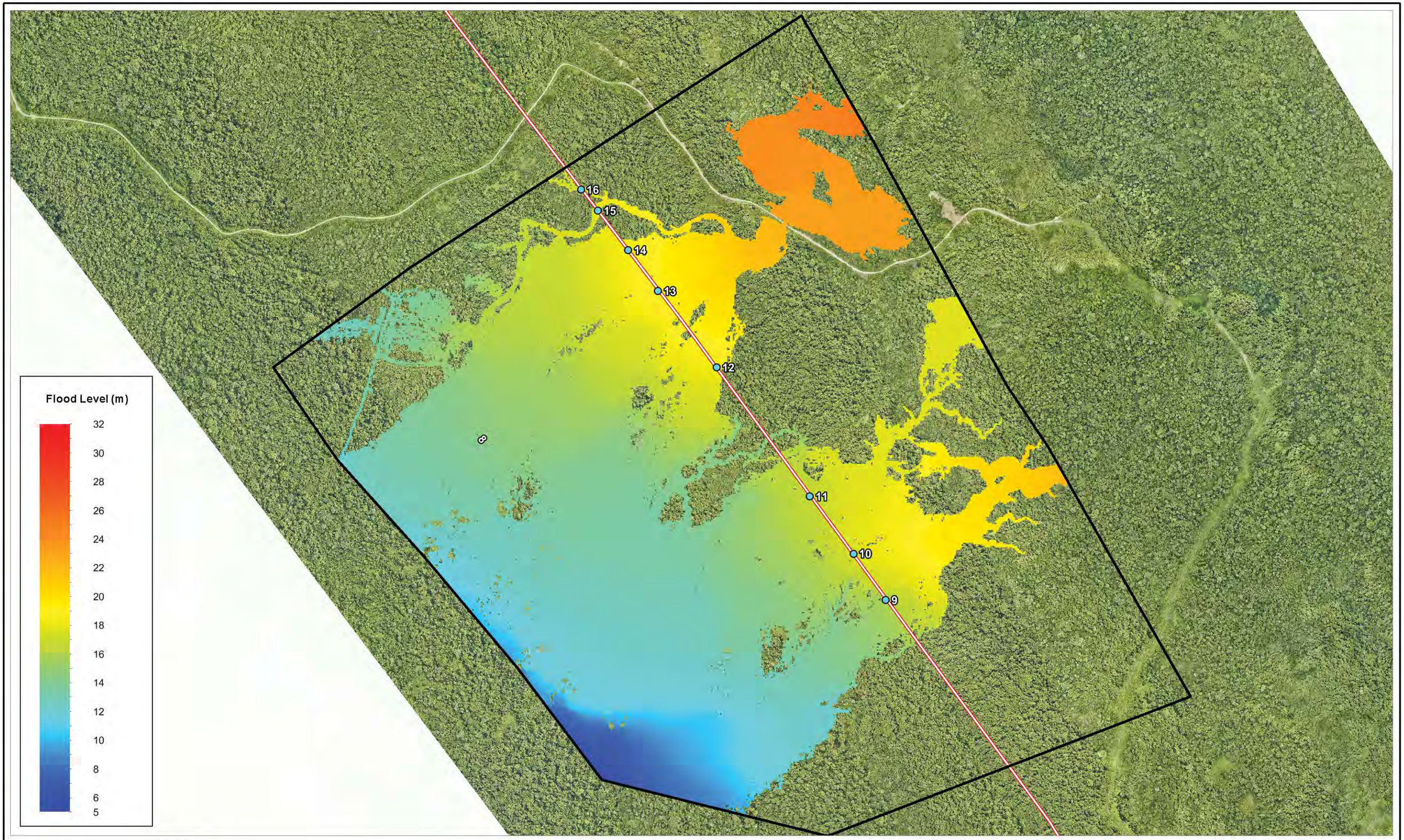
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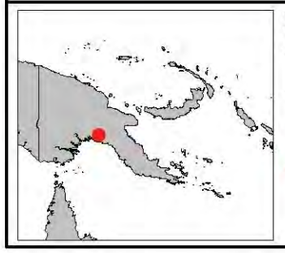
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Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S13 Flood Levels - 50 year event

Figure: D-63

Rev: A

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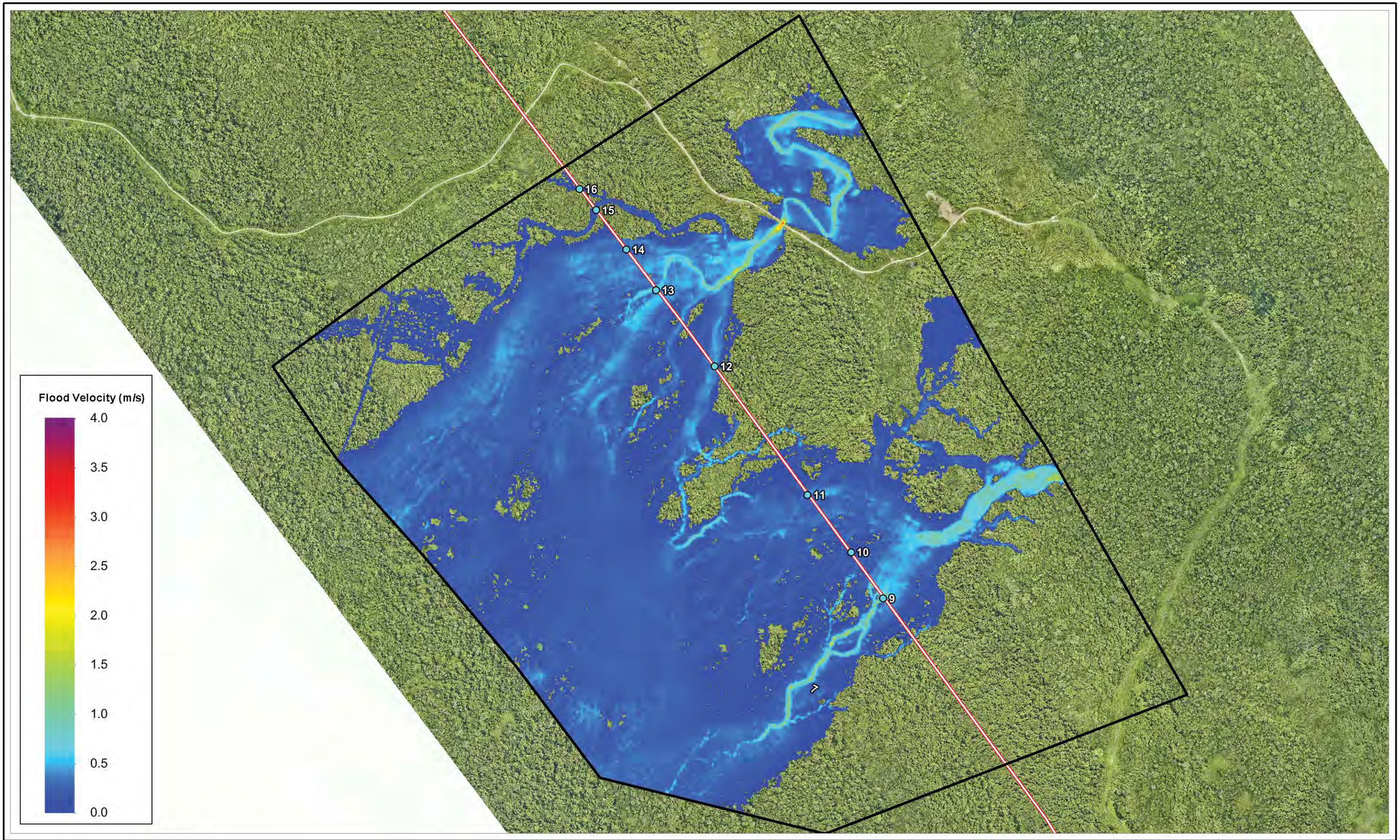
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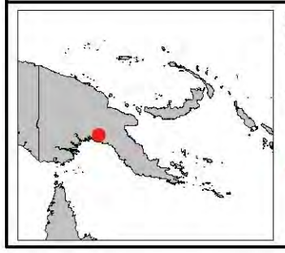
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S13 Flood Velocity - 50 year event

Figure: D-64

Rev: A

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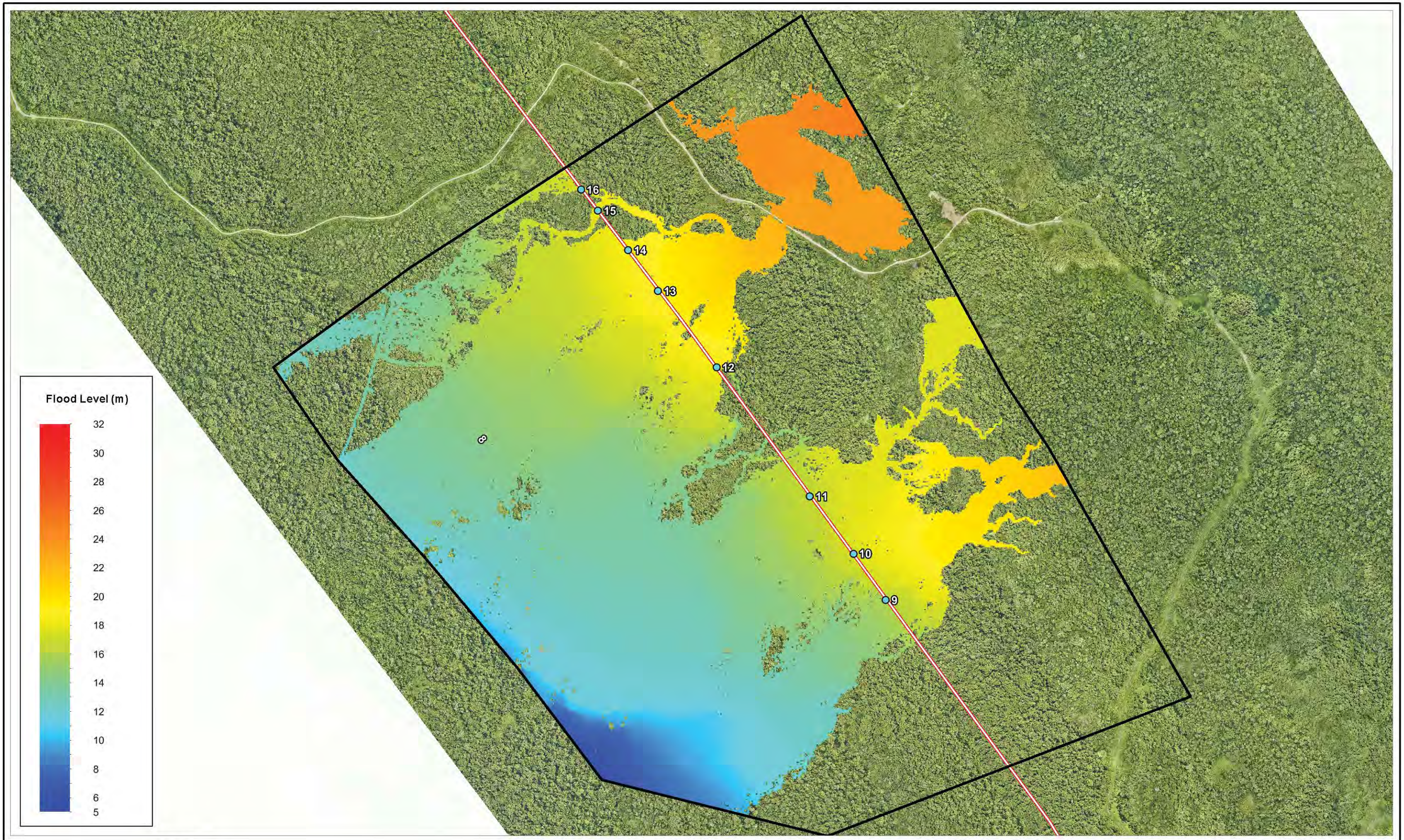
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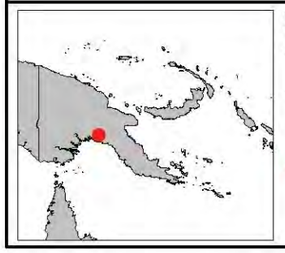
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S13 Flood Levels - 100 year event

Figure: **D-65**

Rev: **A**

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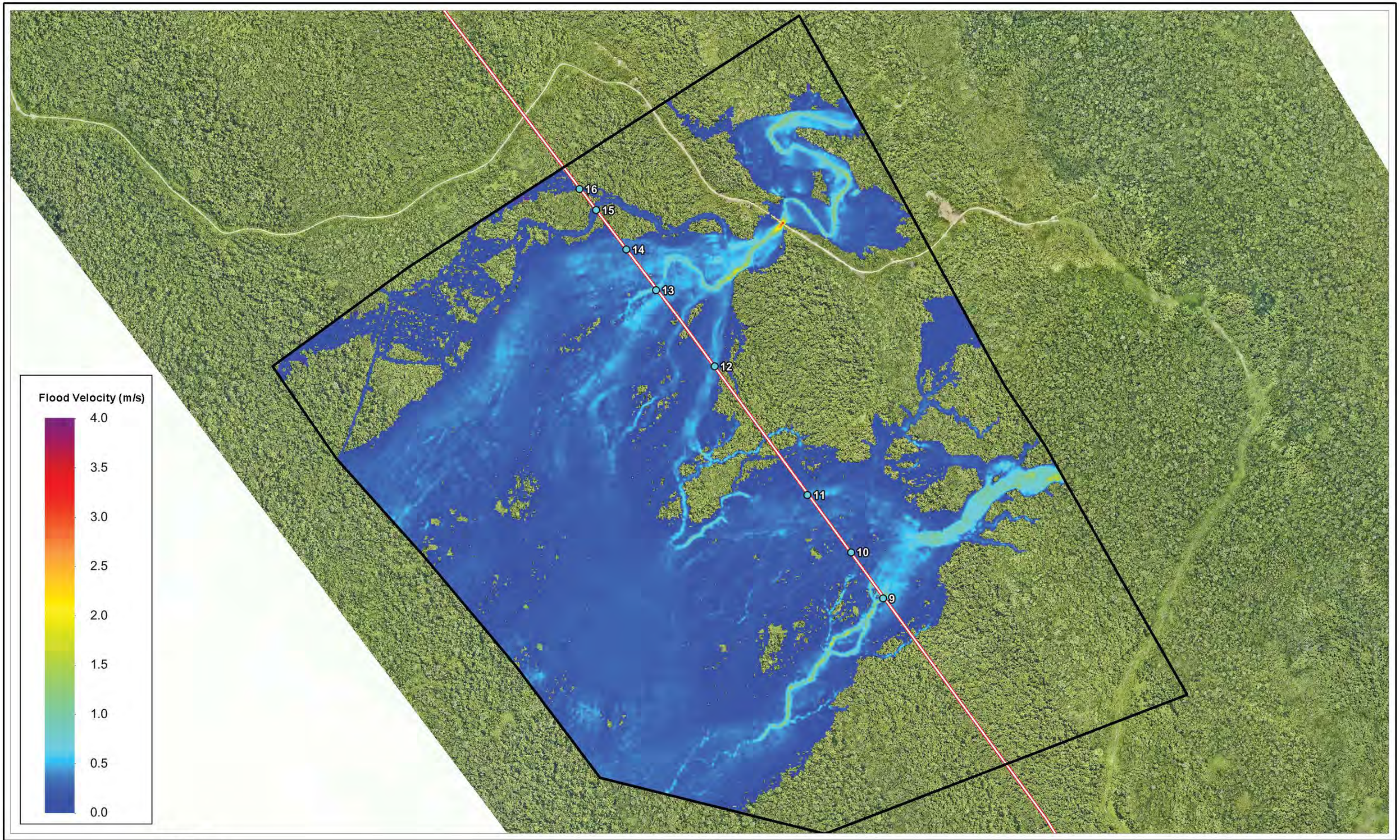
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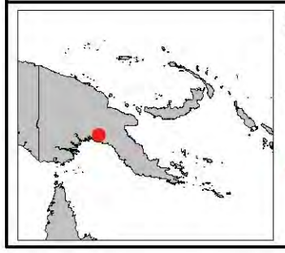
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S13 Flood Velocity - 100 year event

Figure: D-66

Rev: A

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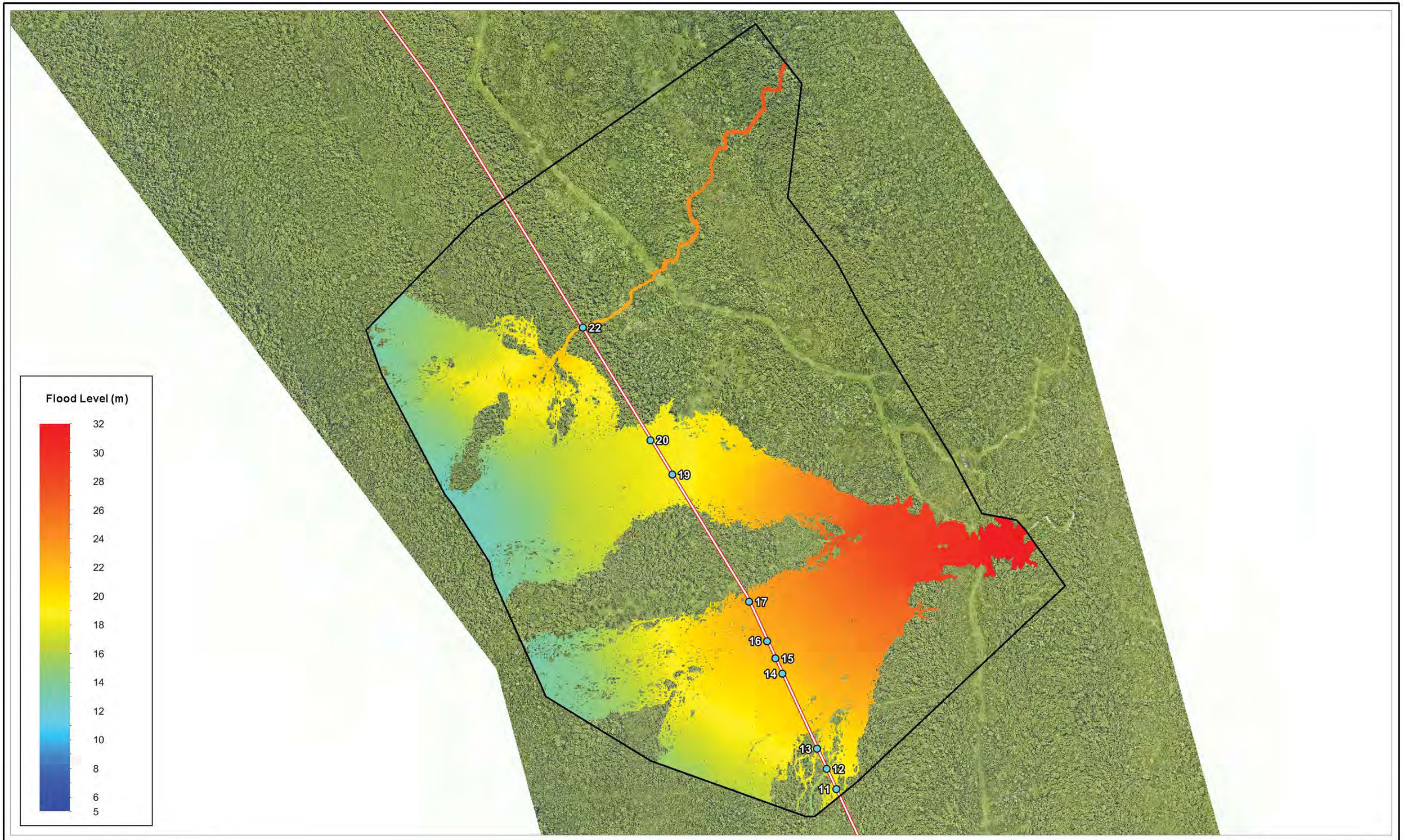
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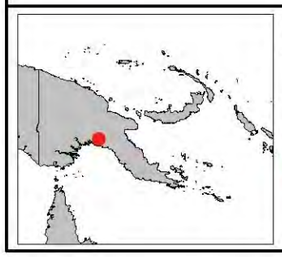
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S14 Flood Levels - 10 year event

Figure: D-67

Rev: A

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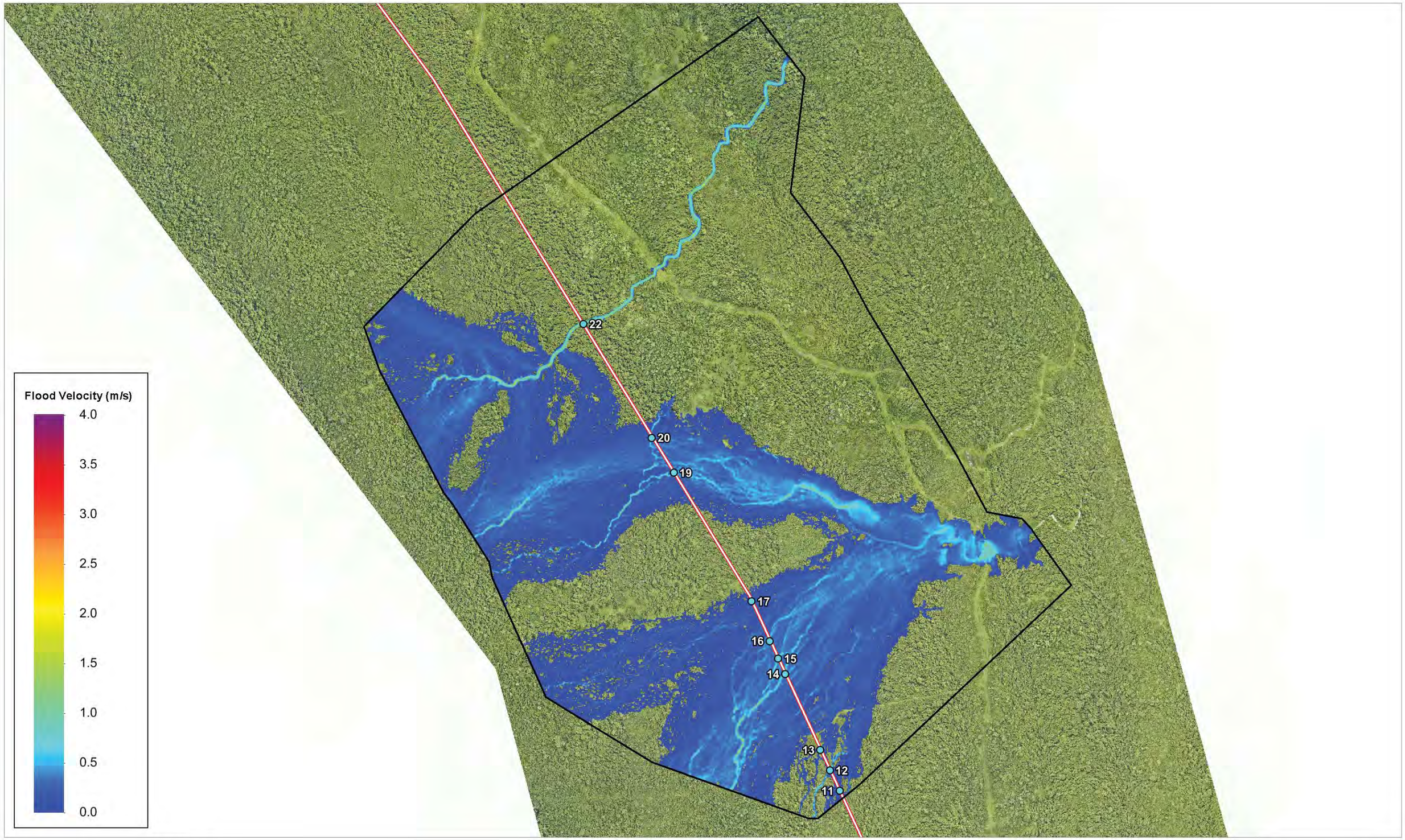
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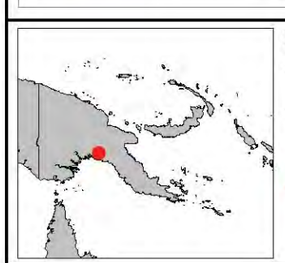
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S14 Flood Velocity - 10 year event

Figure: D-68

Rev: A

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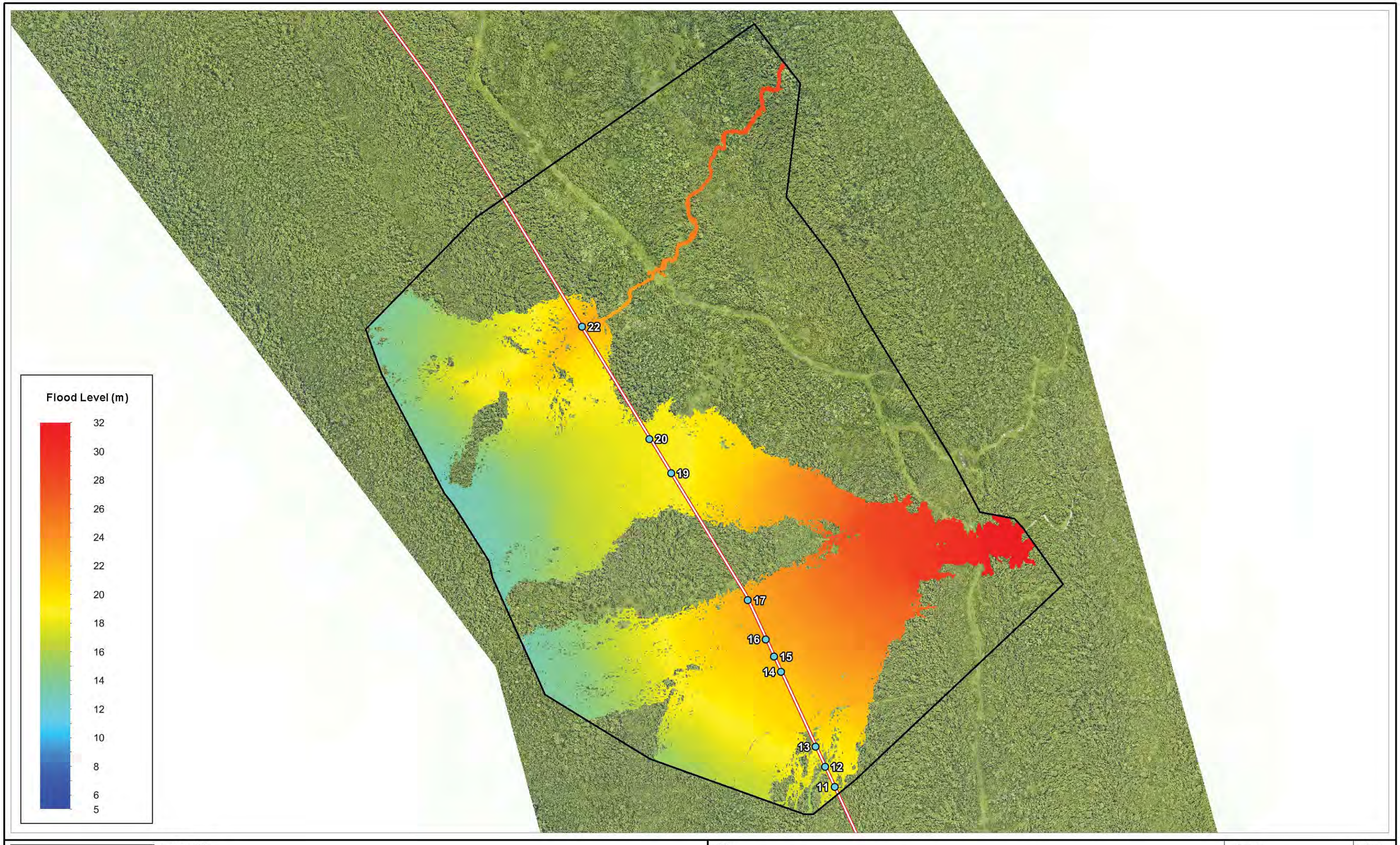
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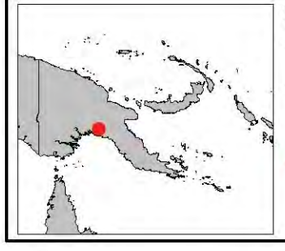
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S14 Flood Levels - 50 year event

Figure: D-69

Rev: A

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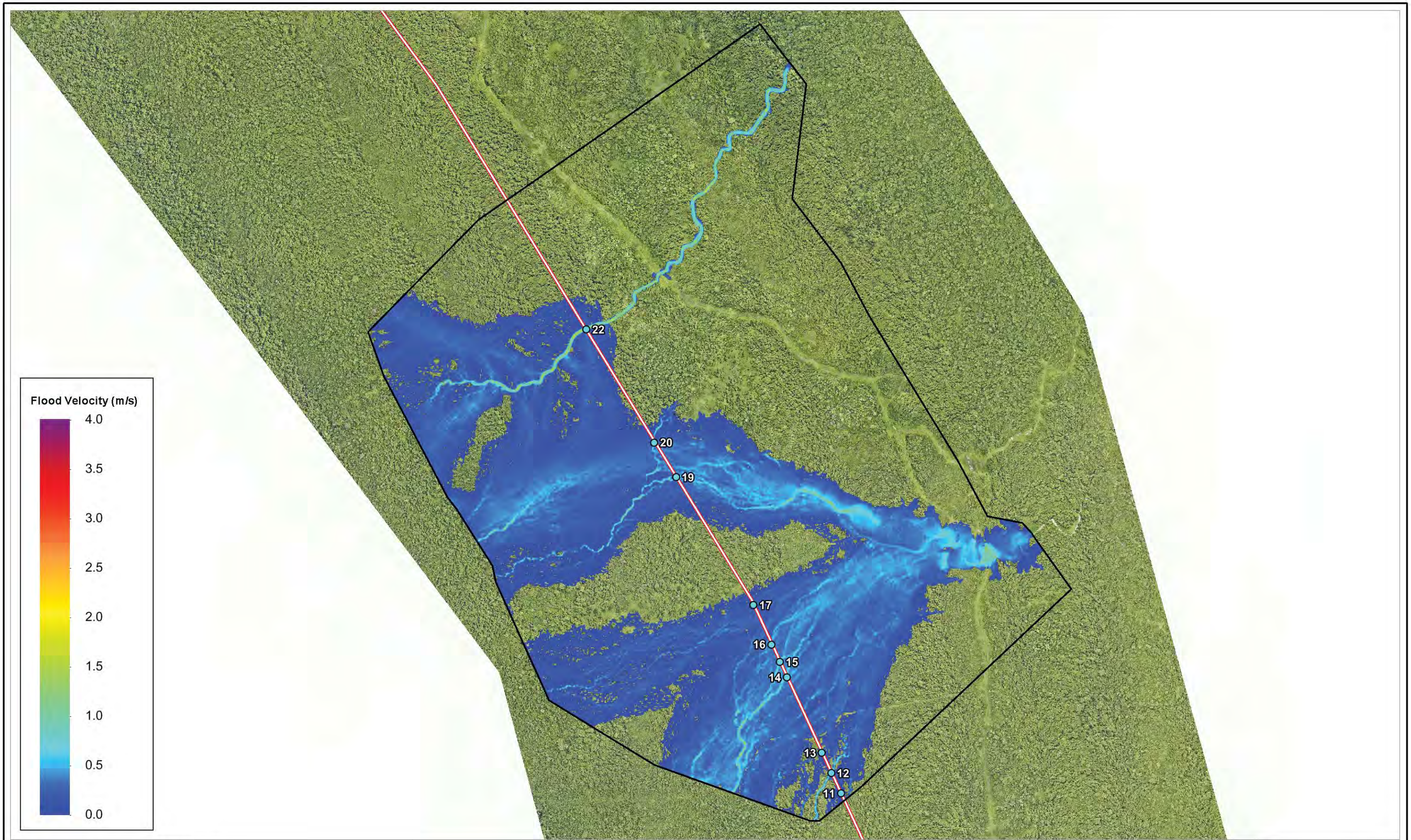
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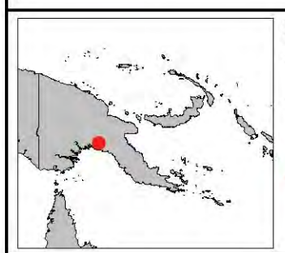
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S14 Flood Velocity - 50 year event

Figure: D-70

Rev: A

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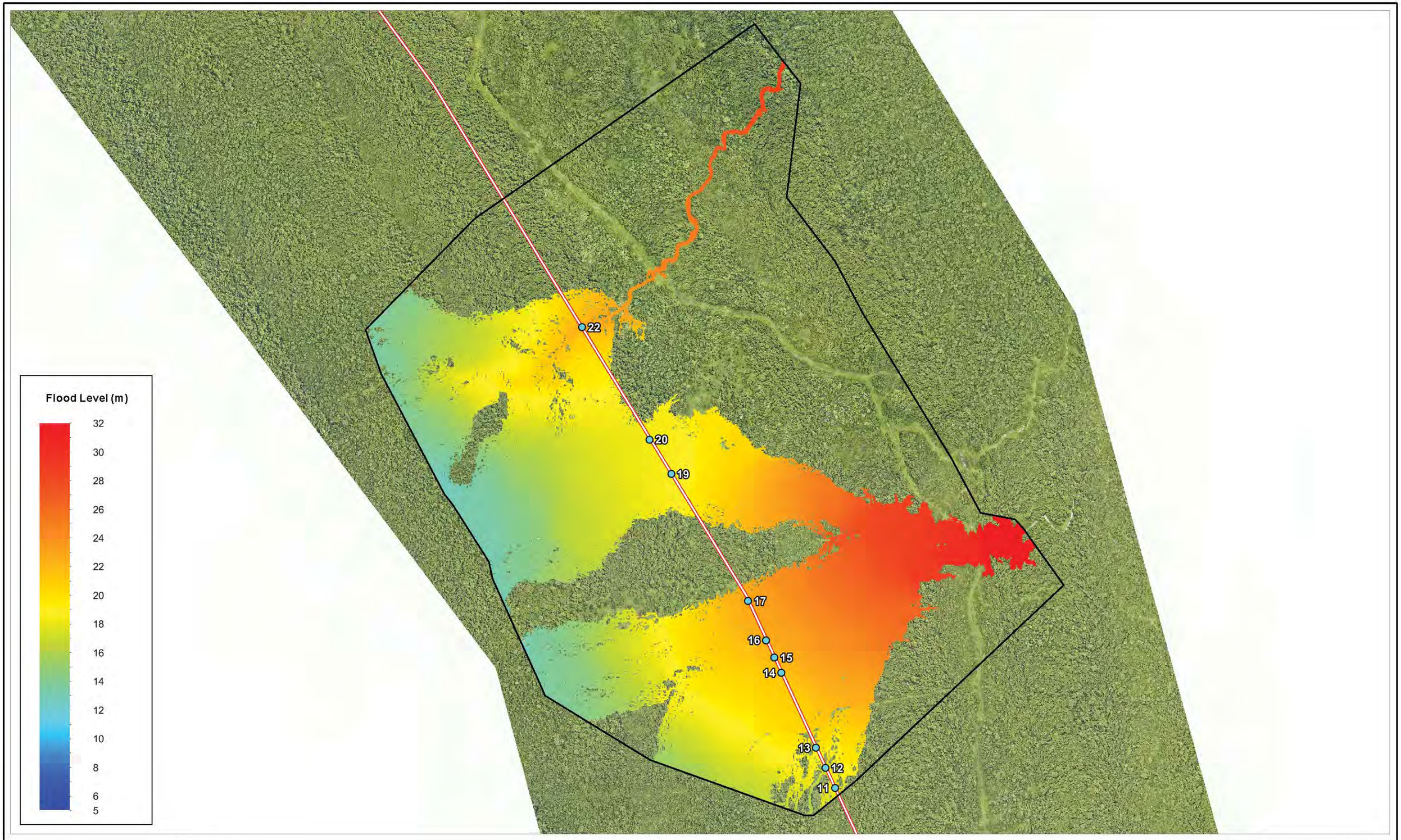
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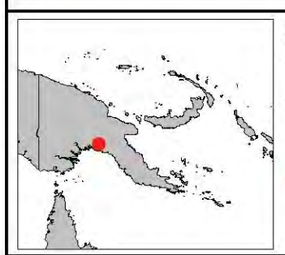
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S14 Flood Levels - 100 year event

Figure: D-71

Rev: A

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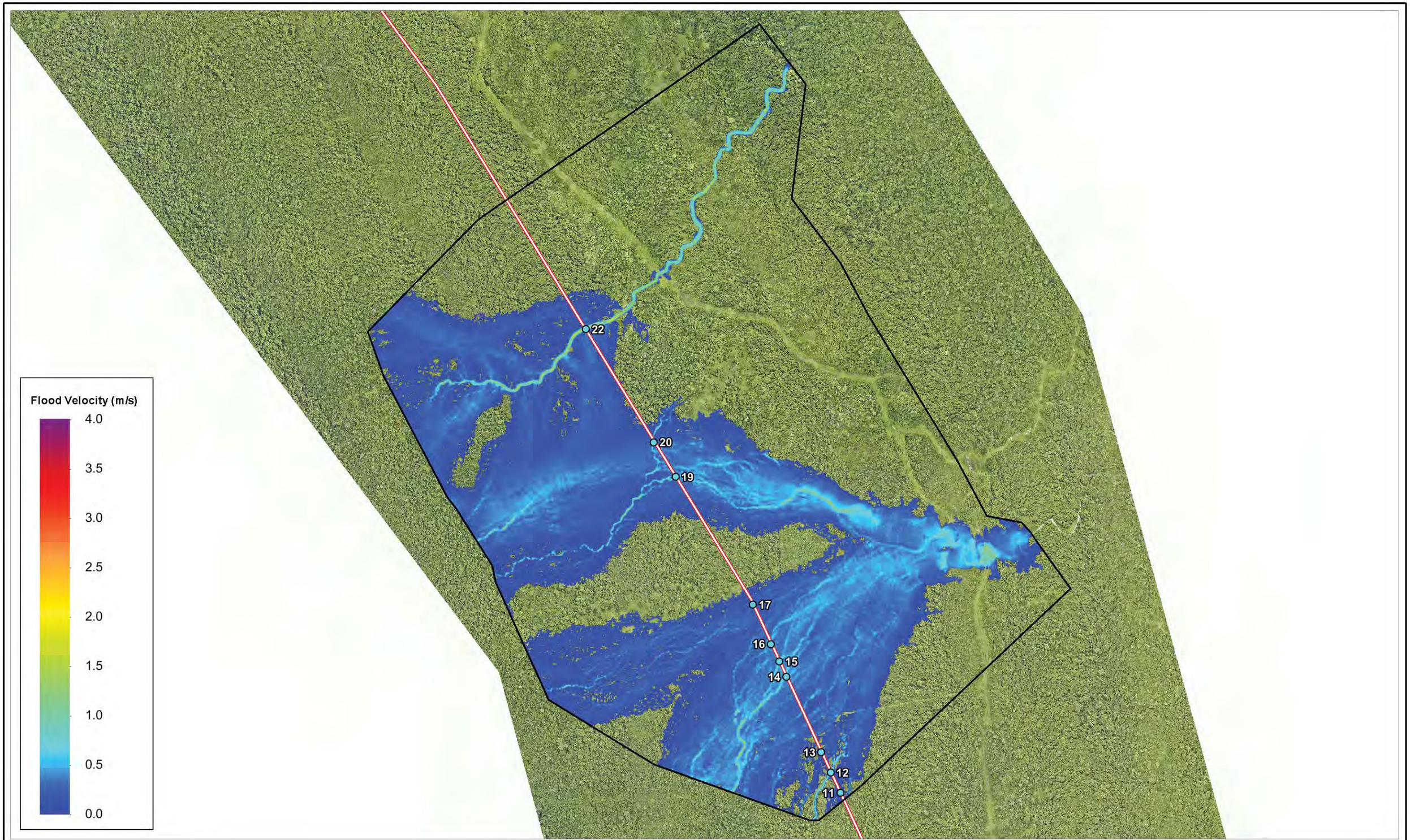
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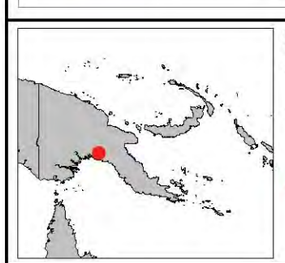
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S14 Flood Velocity - 100 year event

Figure: D-72

Rev: A

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N

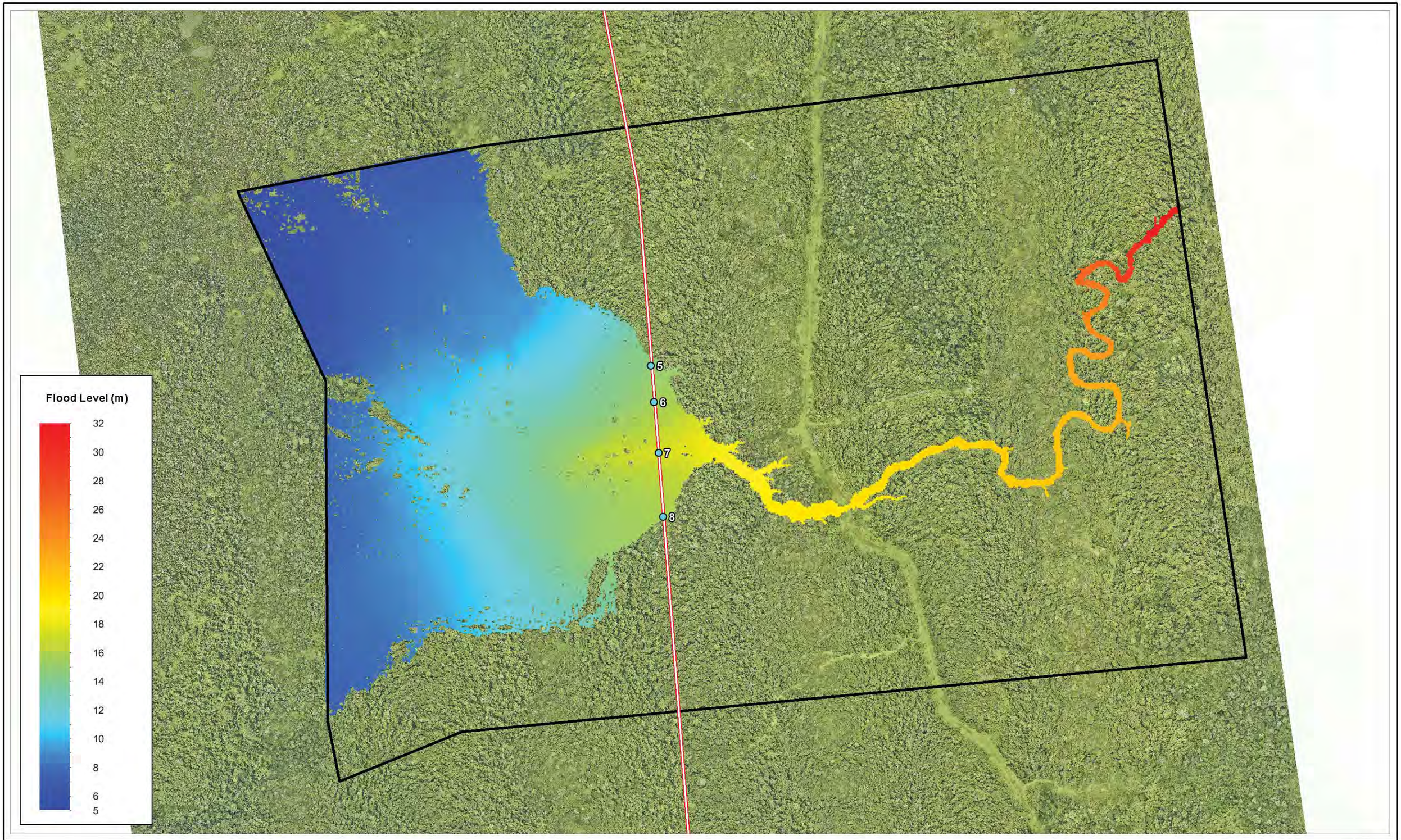
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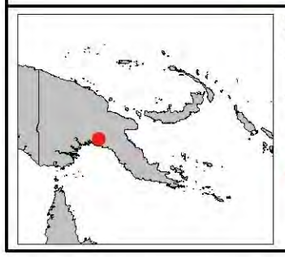
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S16 Flood Levels - 10 year event

Figure: D-73

Rev: A

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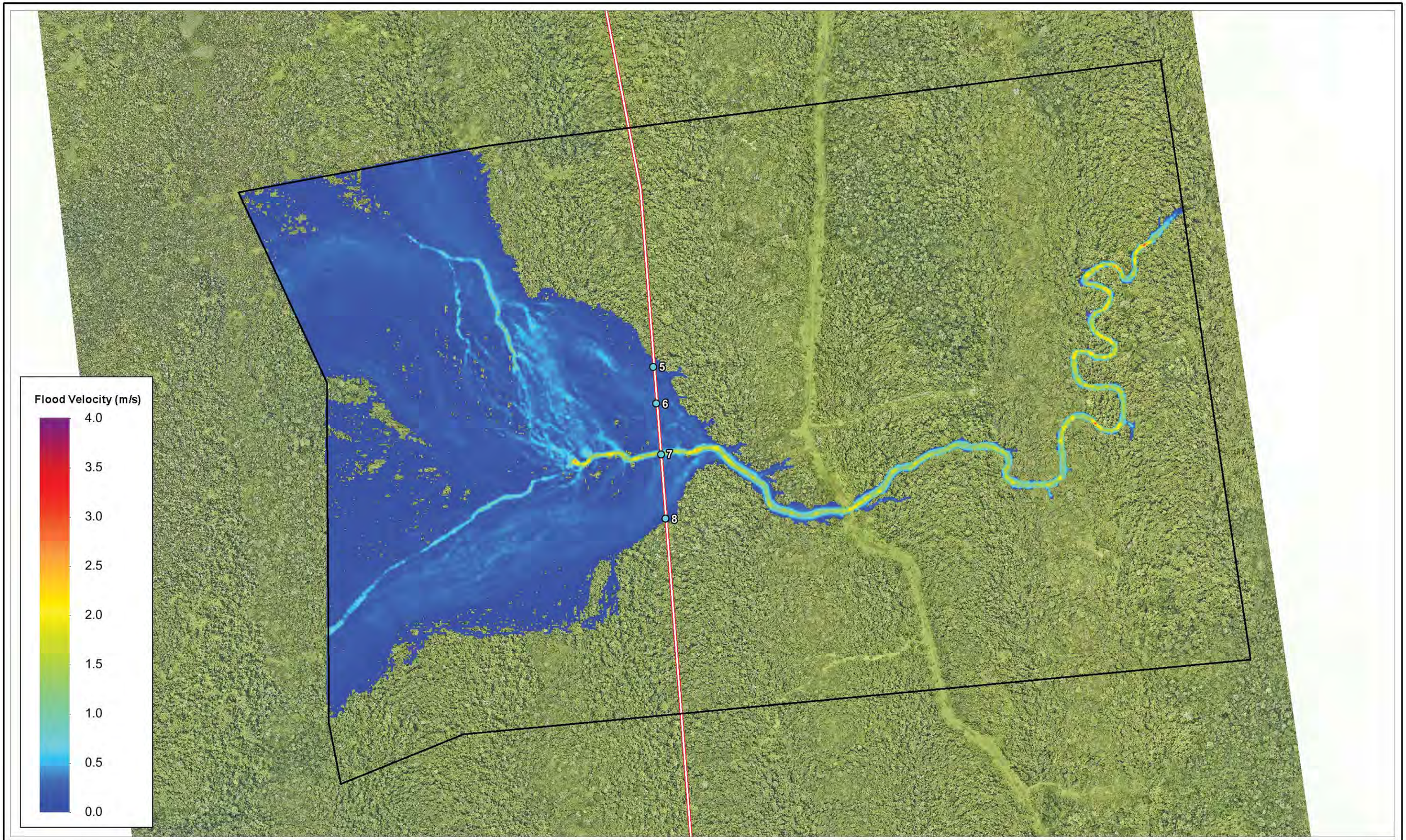
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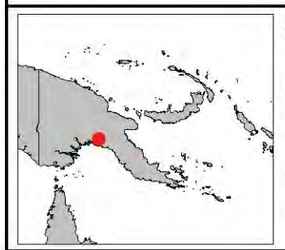
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S16 Flood Velocity - 10 year event

Figure: D-74

Rev: A

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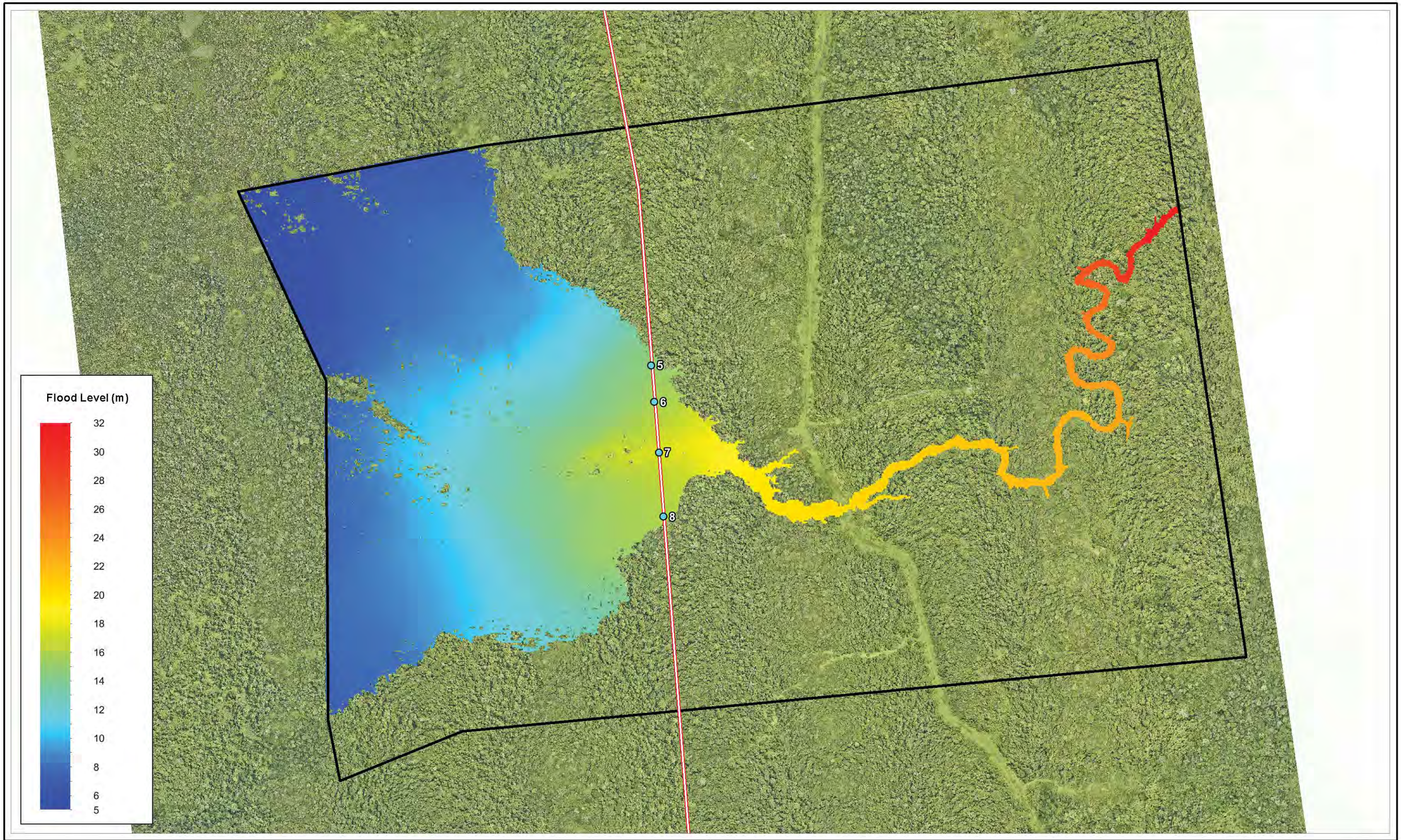
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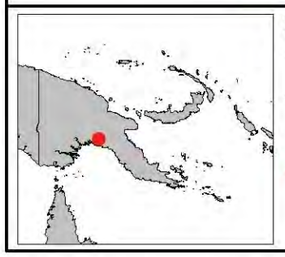
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S16 Flood Levels - 50 year event

Figure: D-75

Rev: A

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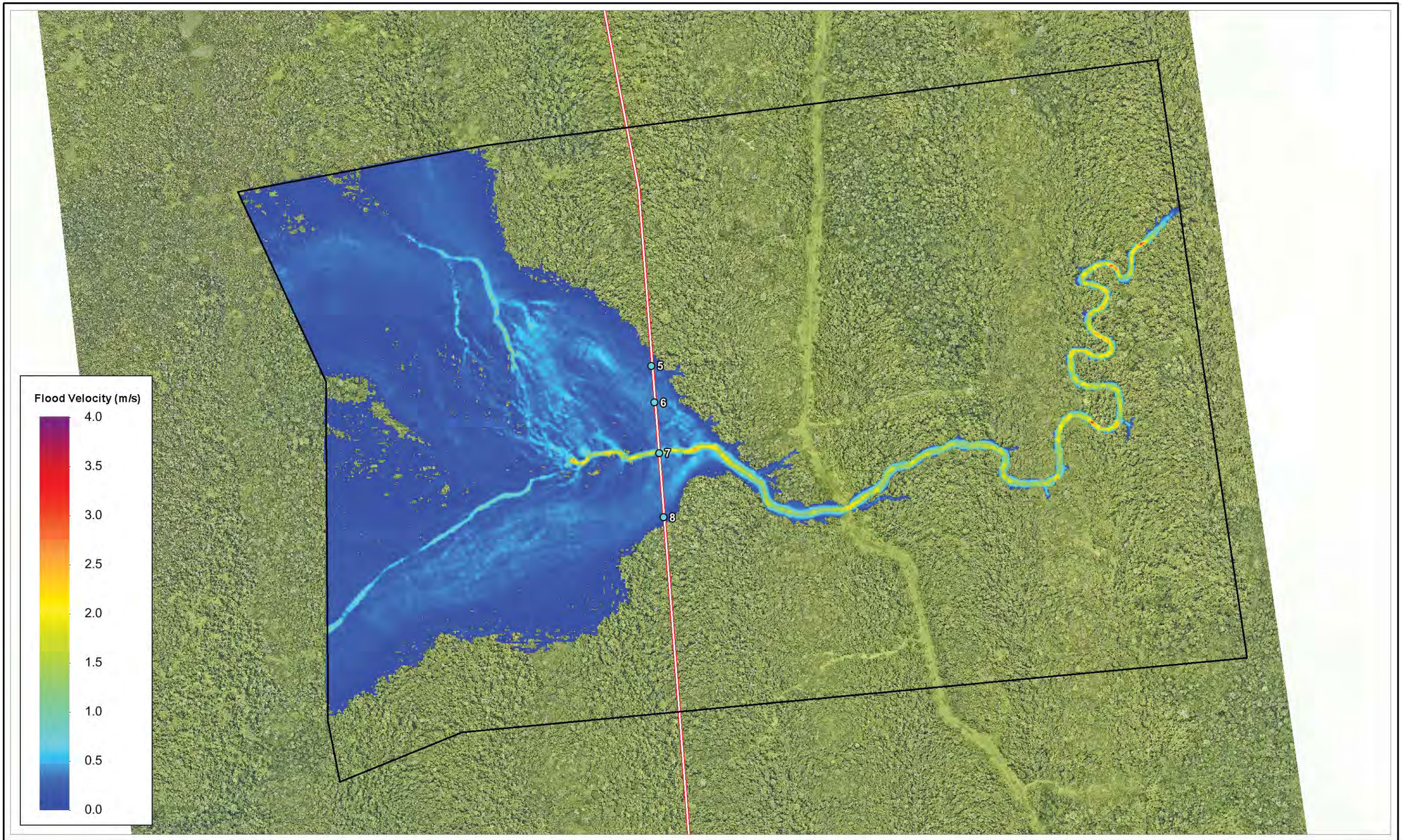
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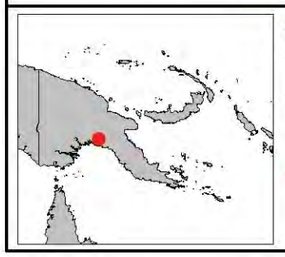
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S16 Flood Velocity - 50 year event

Figure: D-76

Rev: A

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N

0 250 500m

Approx. Scale

BMT WBM

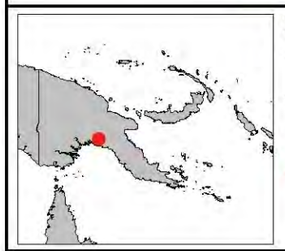
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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_082_170317_S16_v_50y.wor

Flood Level (m)

32
30
28
26
24
22
20
18
16
14
12
10
8
6
5

5
6
7
8



LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S16 Flood Levels - 100 year event

Figure: D-77

Rev: A

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N

0 250 500m

Approx. Scale

BMT WBM

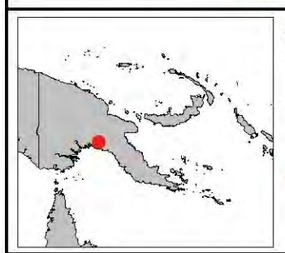
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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_083_170317_S16_h_100y.wor

Flood Velocity (m/s)

4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0

5
6
7
8



LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S16 Flood Velocity - 100 year event

Figure: D-78

Rev: A

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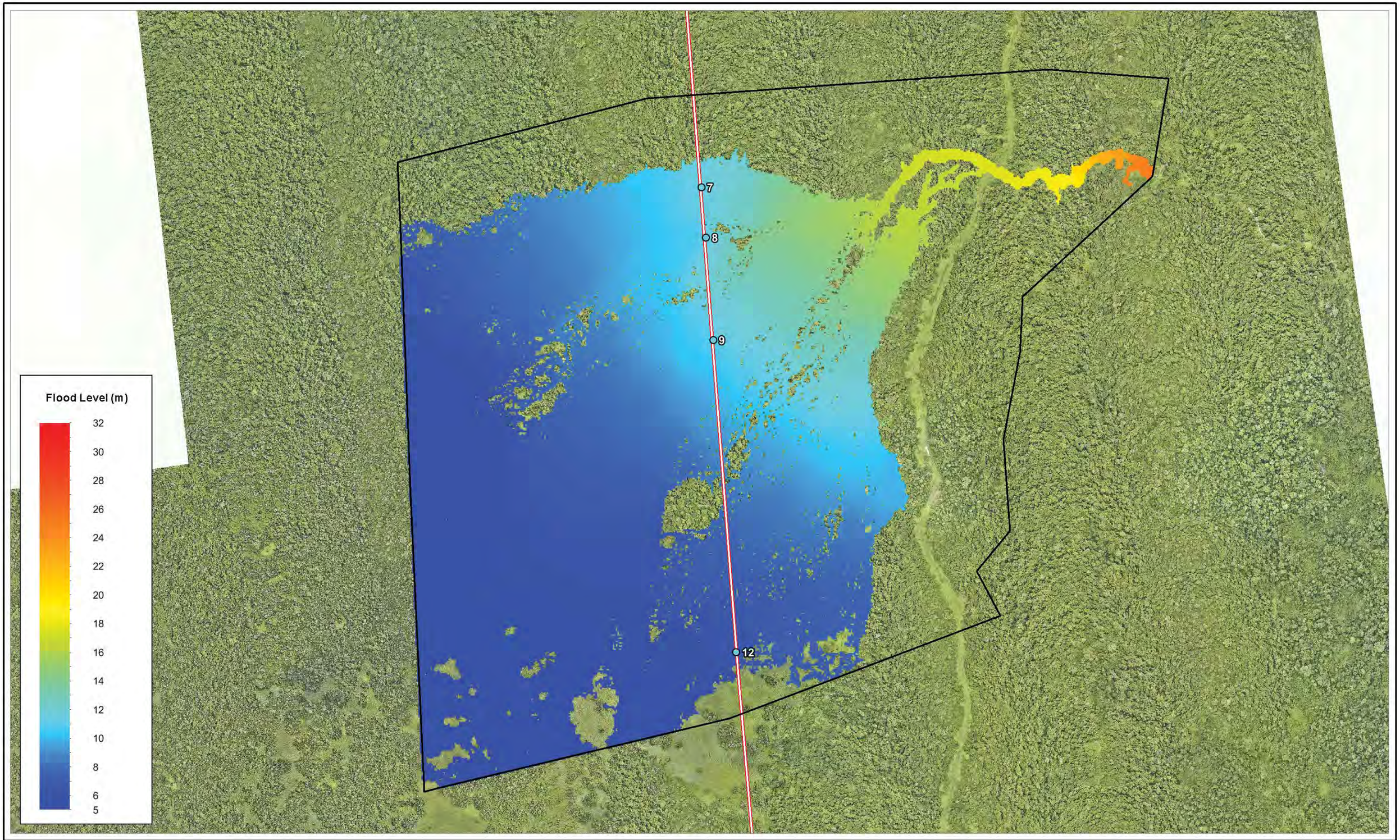
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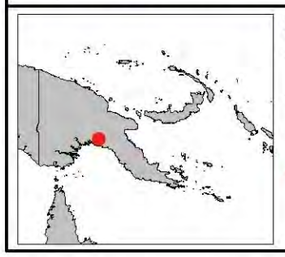
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S17 Flood Levels - 10 year event

Figure: D-79

Rev: A

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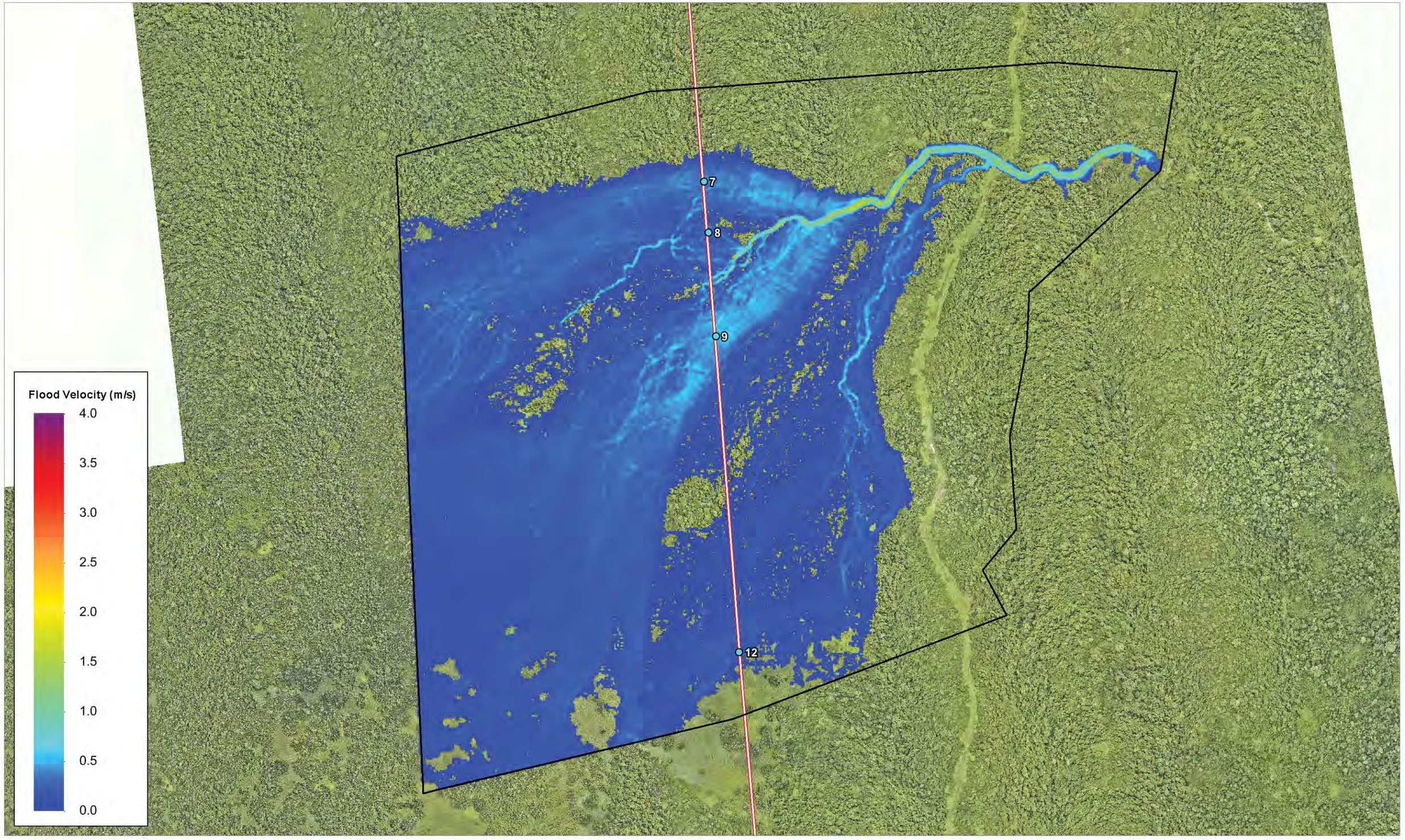
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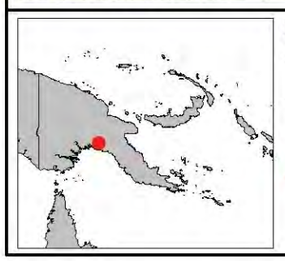
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S17 Flood Velocity - 10 year event

Figure: D-80

Rev: A

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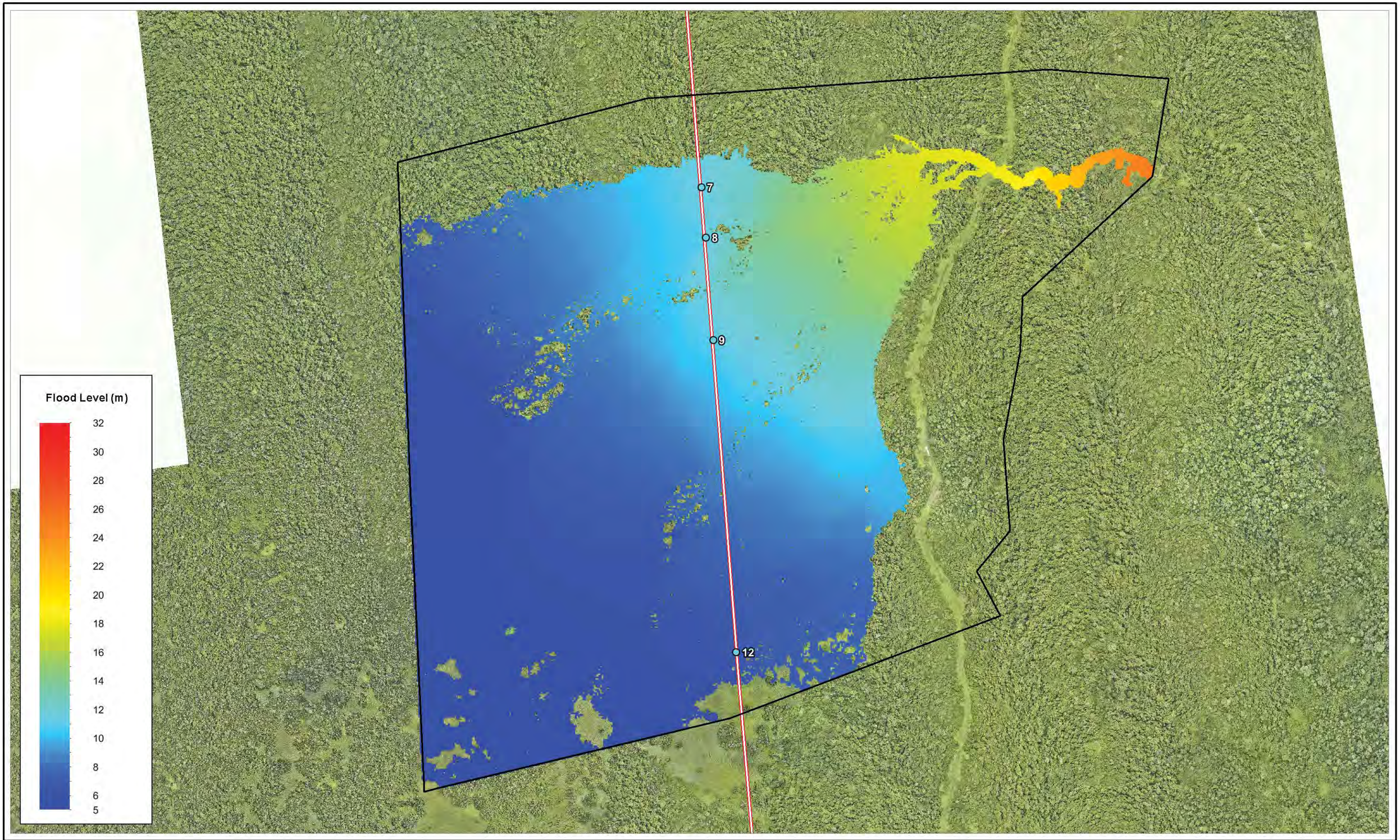
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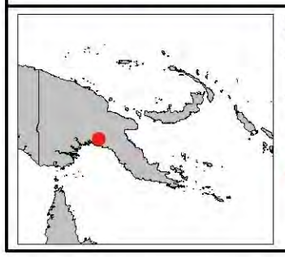
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:
Model S17 Flood Levels - 50 year event

Figure: D-81

Rev: A

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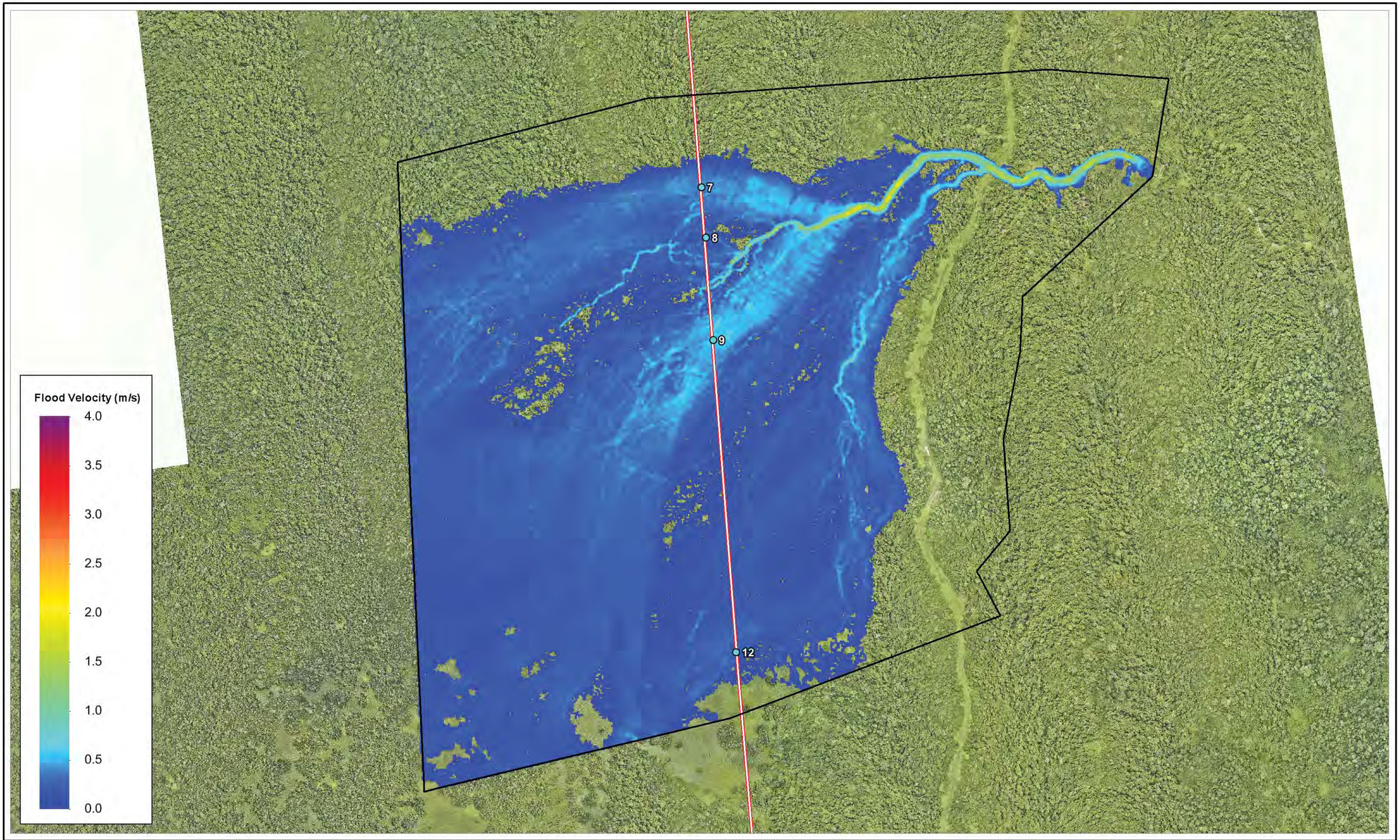
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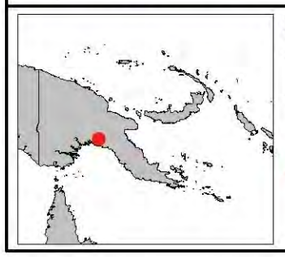
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S17 Flood Velocity - 50 year event

Figure: D-82

Rev: A

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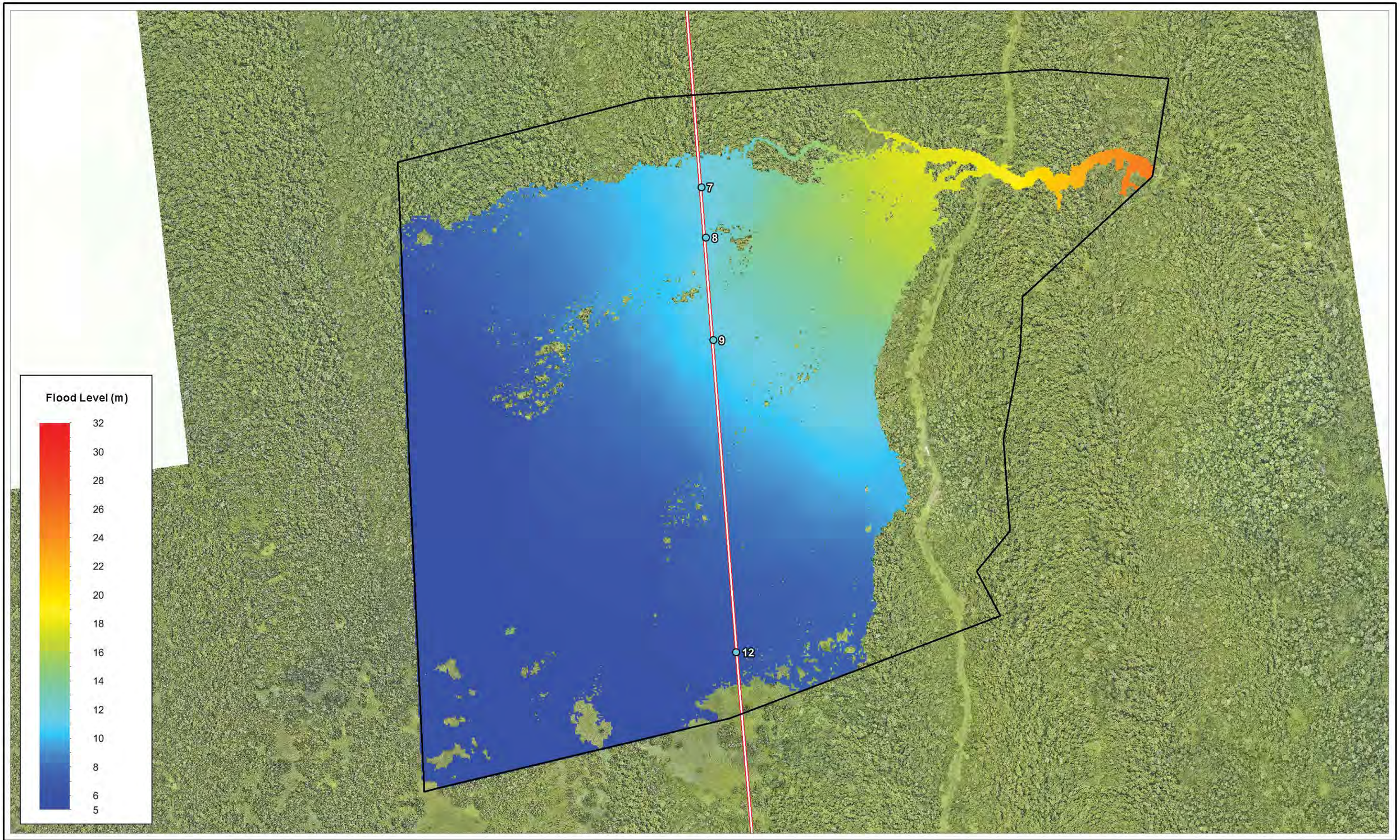
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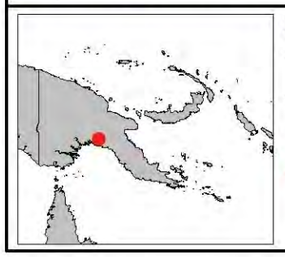
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:
Model S17 Flood Levels - 100 year event

Figure: D-83

Rev: A

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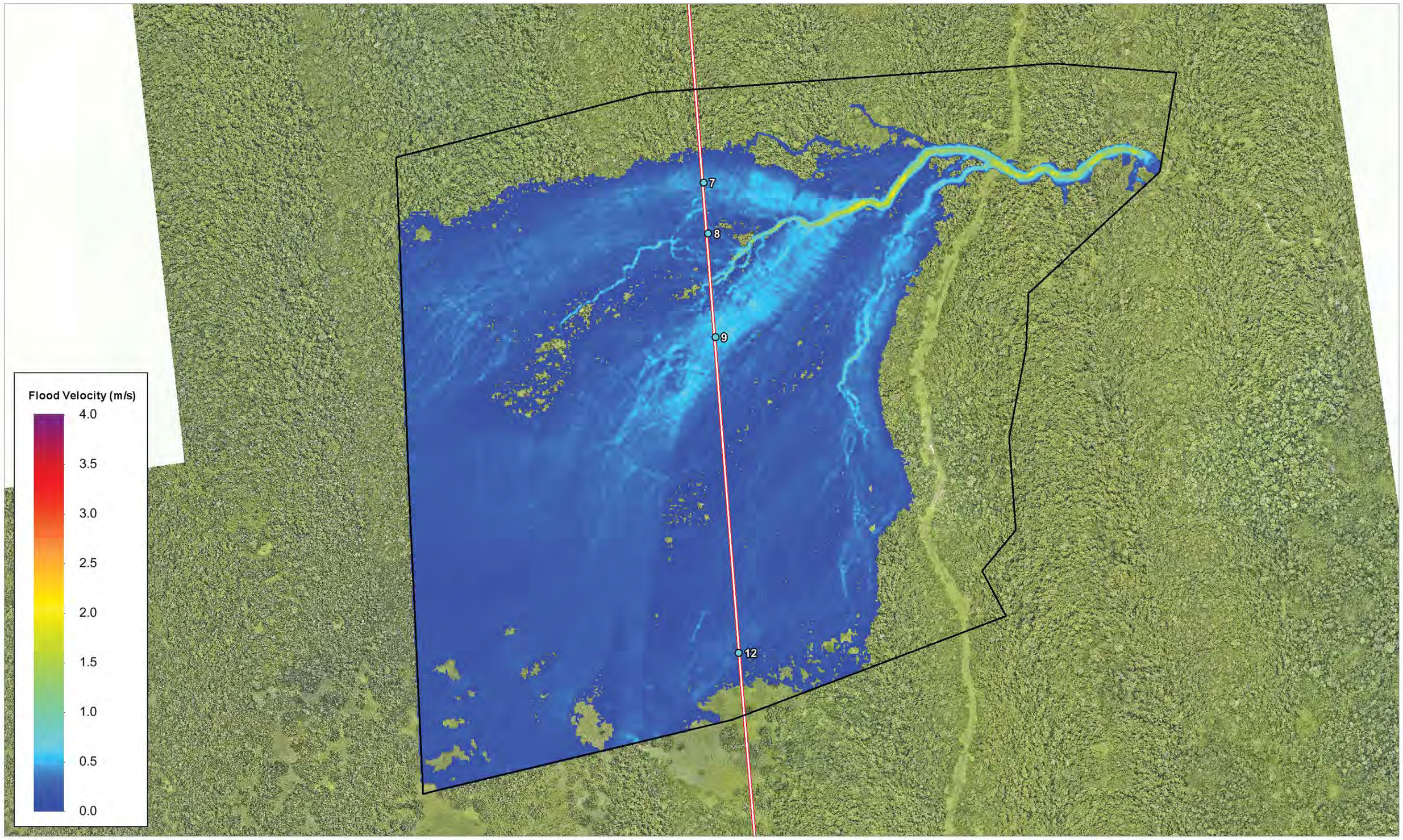
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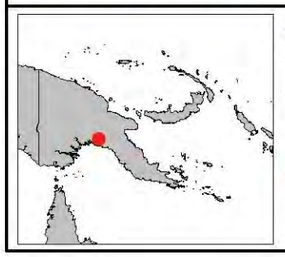
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S17 Flood Velocity - 100 year event

Figure: **D-84**

Rev: **A**

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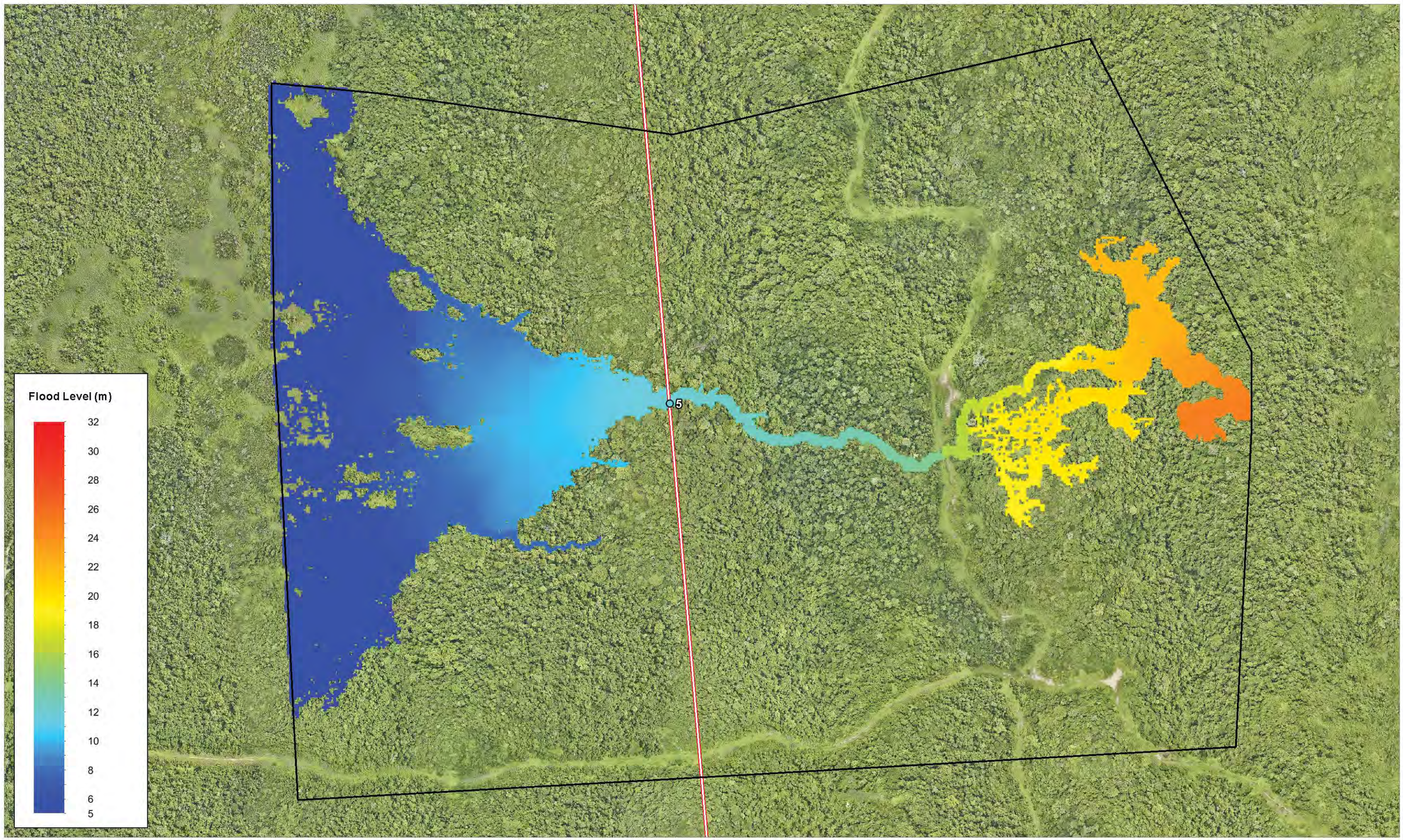
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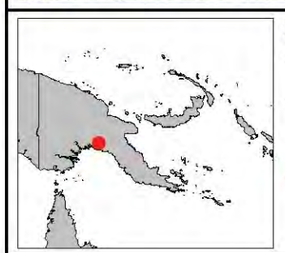
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S18 Flood Levels - 10 year event

Figure: D-85

Rev: A

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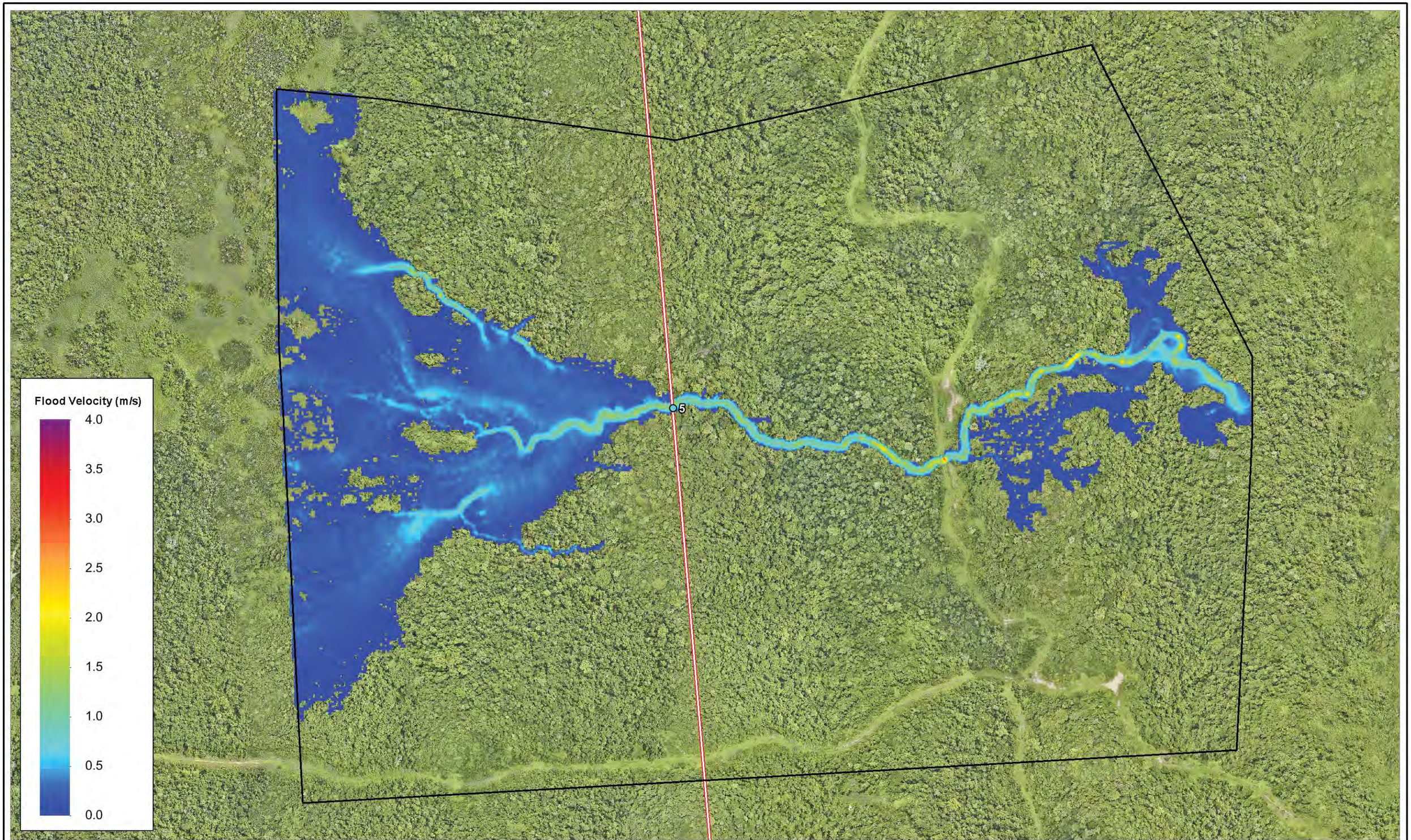
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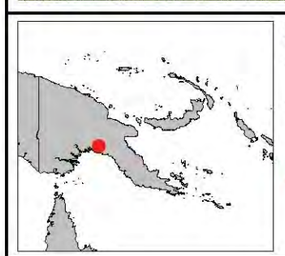
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S18 Flood Velocity - 10 year event

Figure: D-86

Rev: A

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N

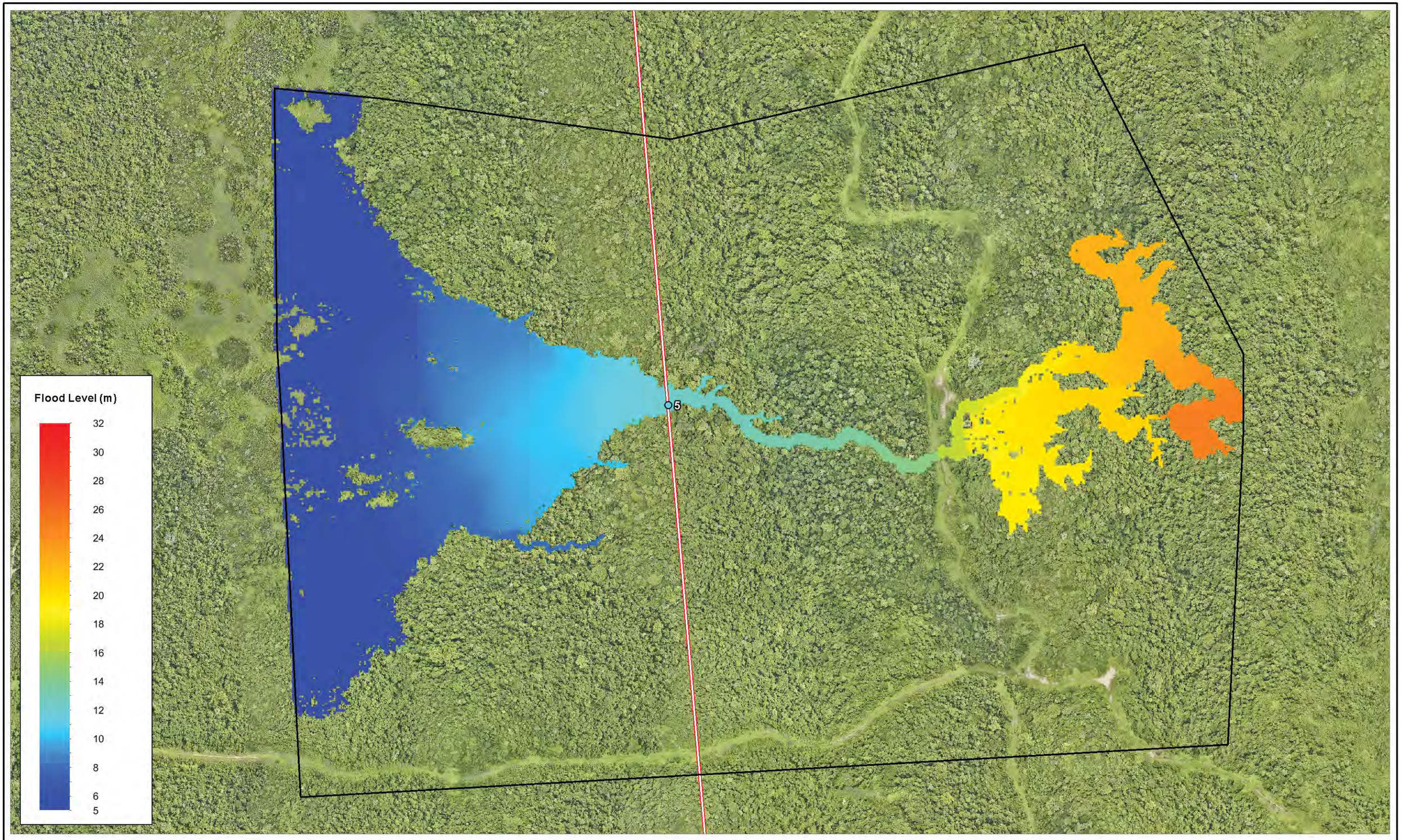
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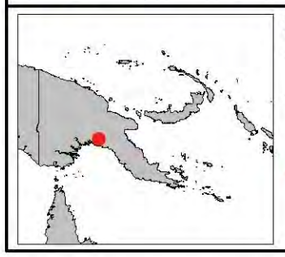
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S18 Flood Levels - 50 year event

Figure: D-87

Rev: A

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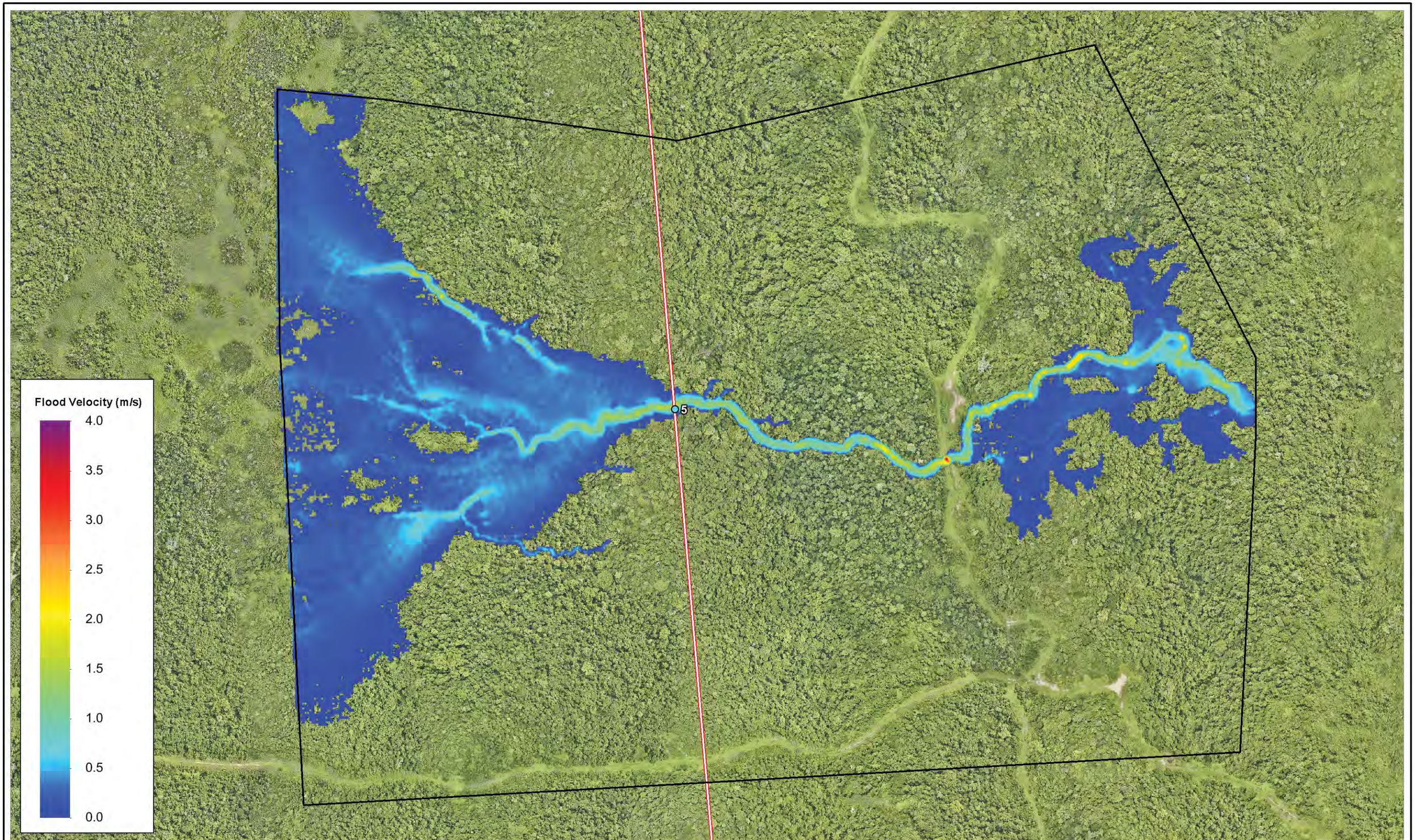
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Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S18 Flood Velocity - 50 year event

Figure: **D-88**

Rev: **A**

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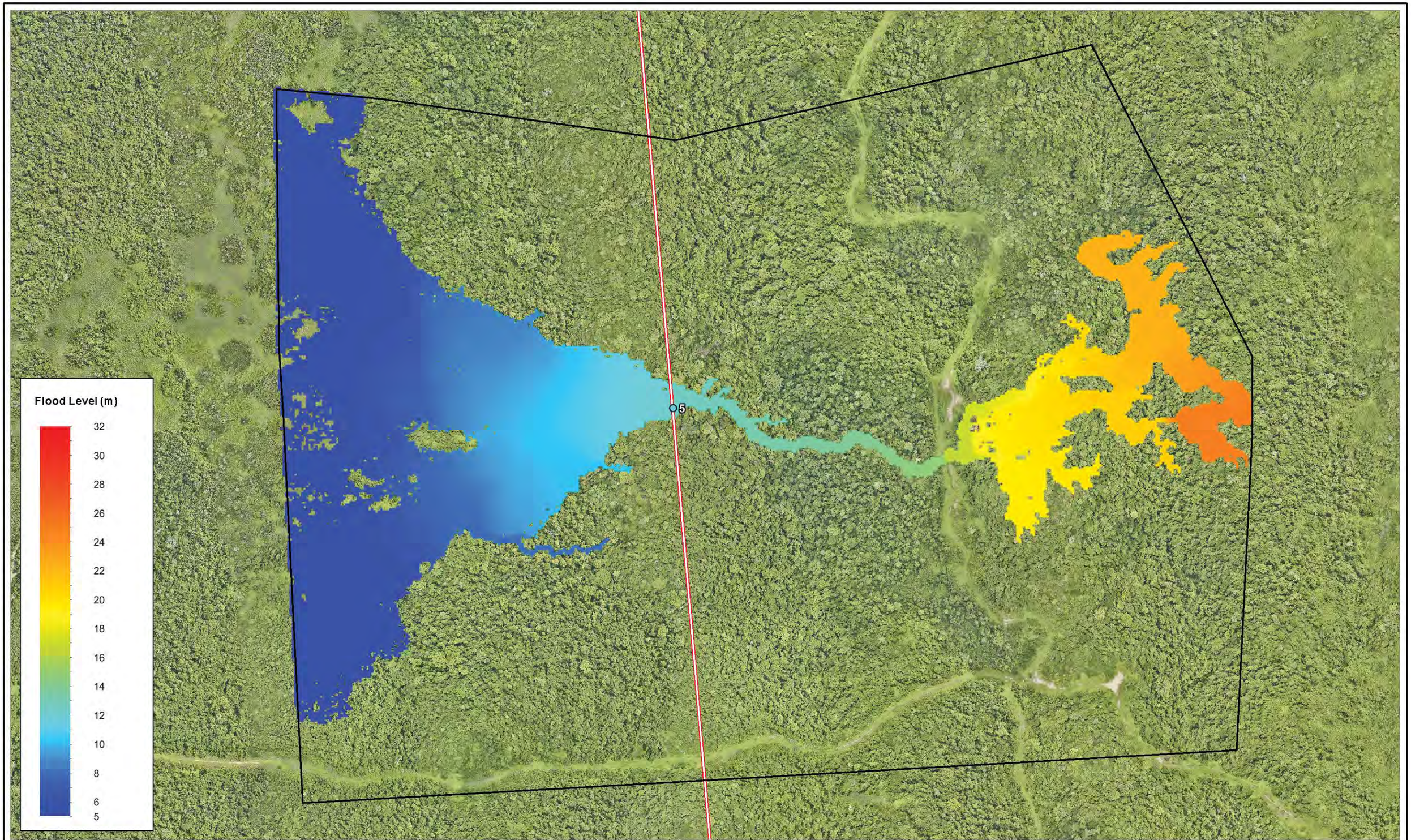
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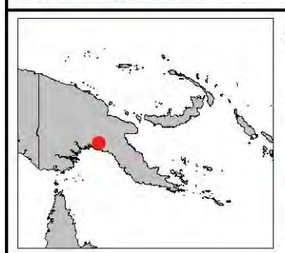
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S18 Flood Levels - 100 year event

Figure: D-89

Rev: A

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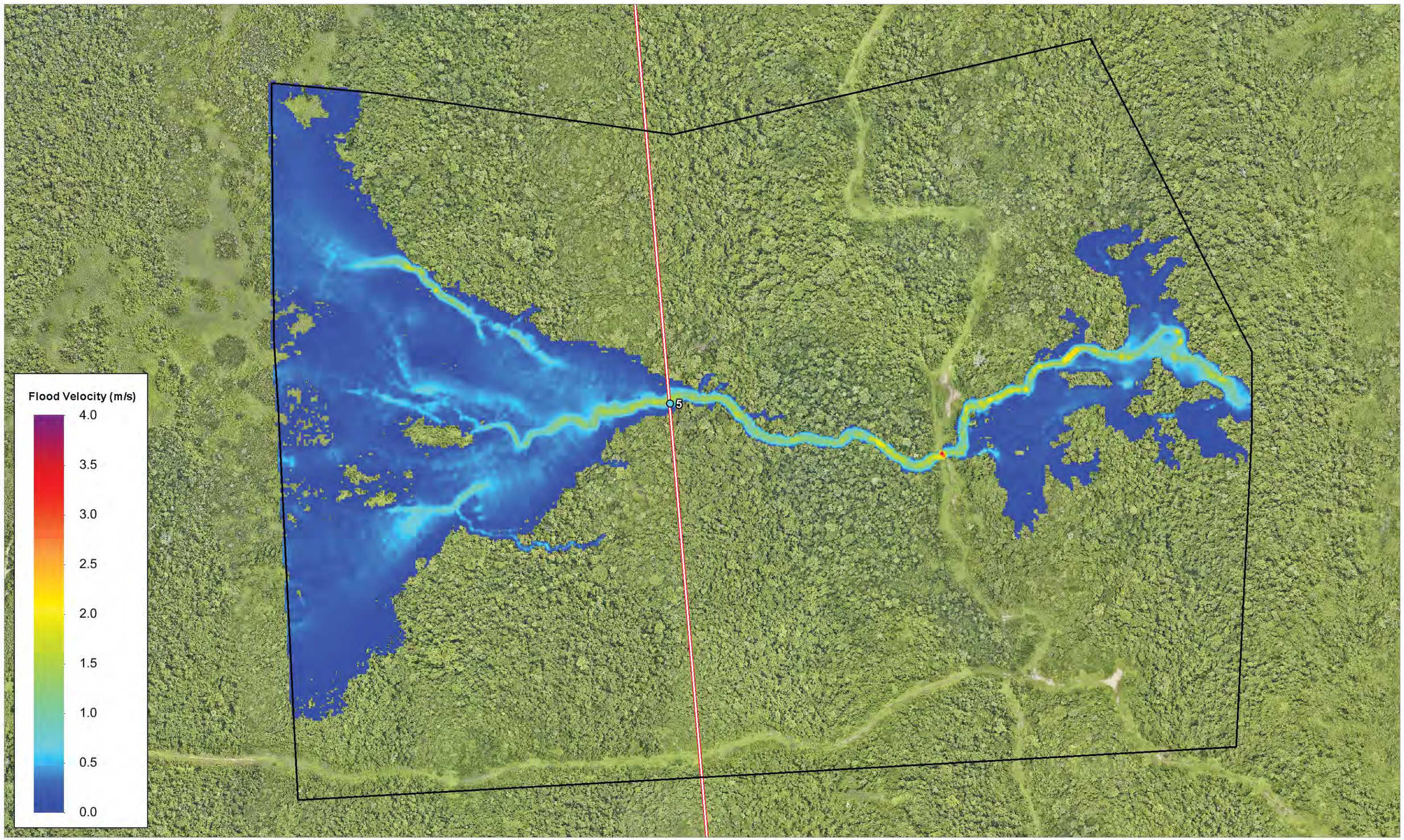
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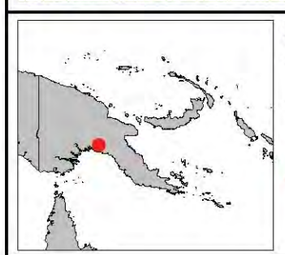
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S18 Flood Velocity - 100 year event

Figure: **D-90**

Rev: **A**

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N

0 200 400m

Approx. Scale

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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_096_170317_S18_v_100y.wor

Flood Level (m)

8
7
6
5
4
3
2
1
0

7
19
9
11
13

LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:
Model S20 Flood Levels - 10 year event

Figure: D-91

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

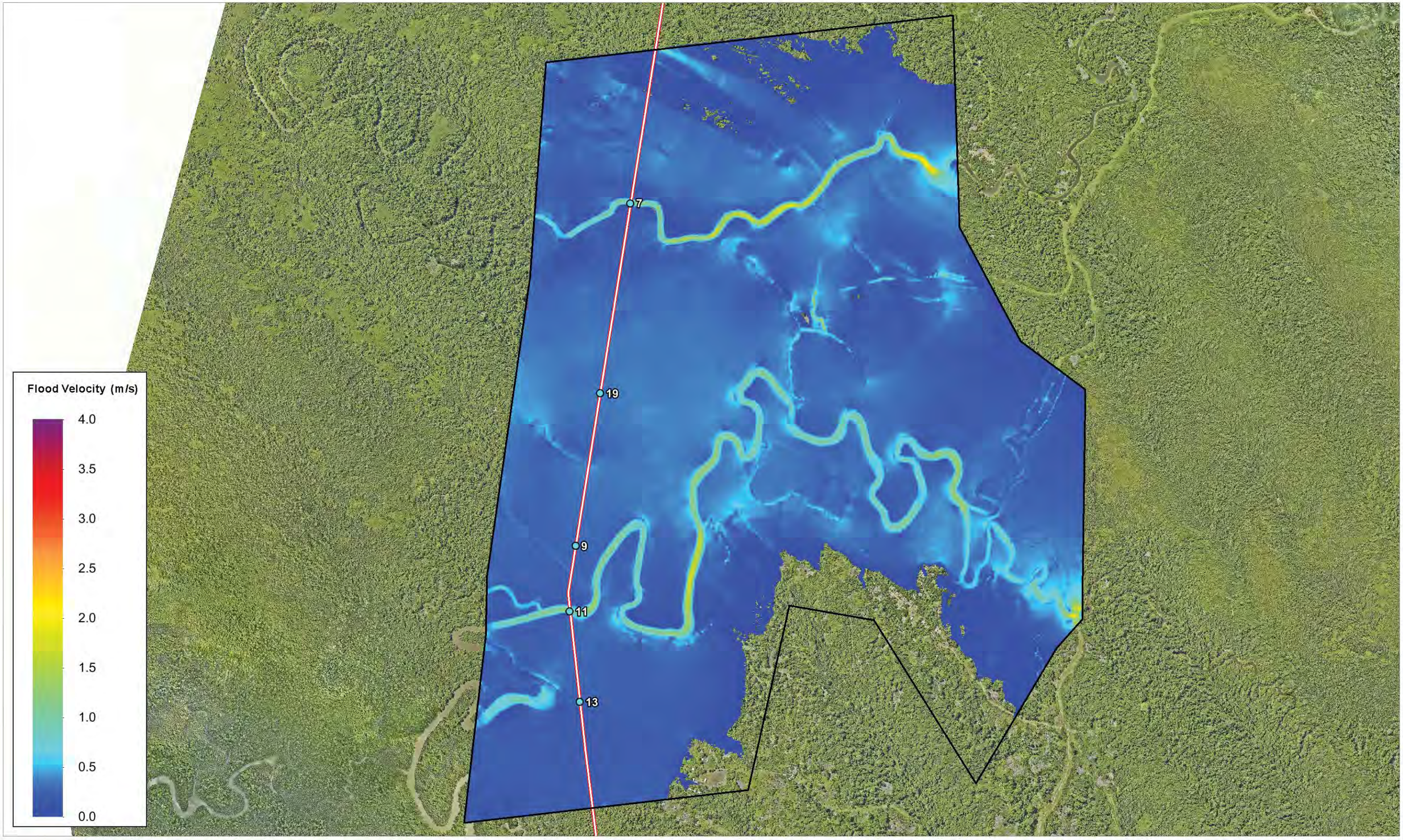
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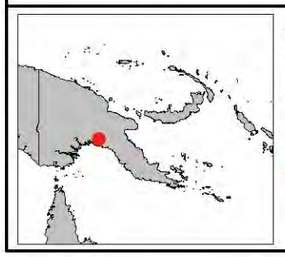
0 500 1,000m

Approx. Scale

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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_097_170317_S20_h_10y.wor





LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S20 Flood Velocity - 10 year event

Figure: D-92

Rev: A

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N

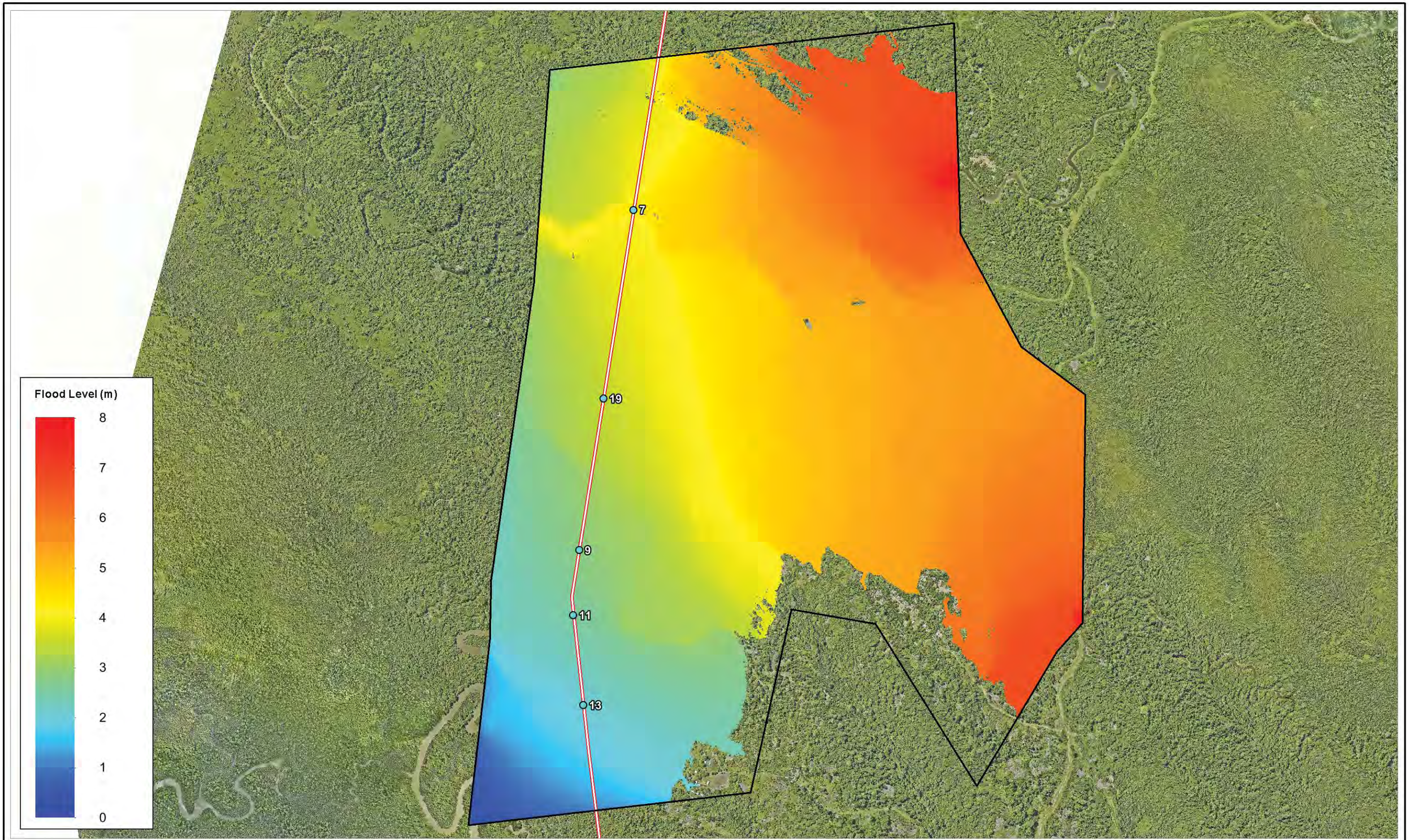
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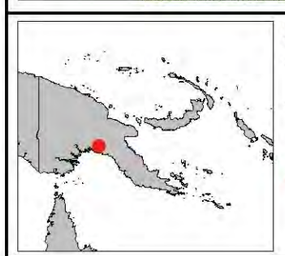
Approx. Scale

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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_098_170317_S20_v_10y.wor





LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S20 Flood Levels - 50 year event

Figure: D-93

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

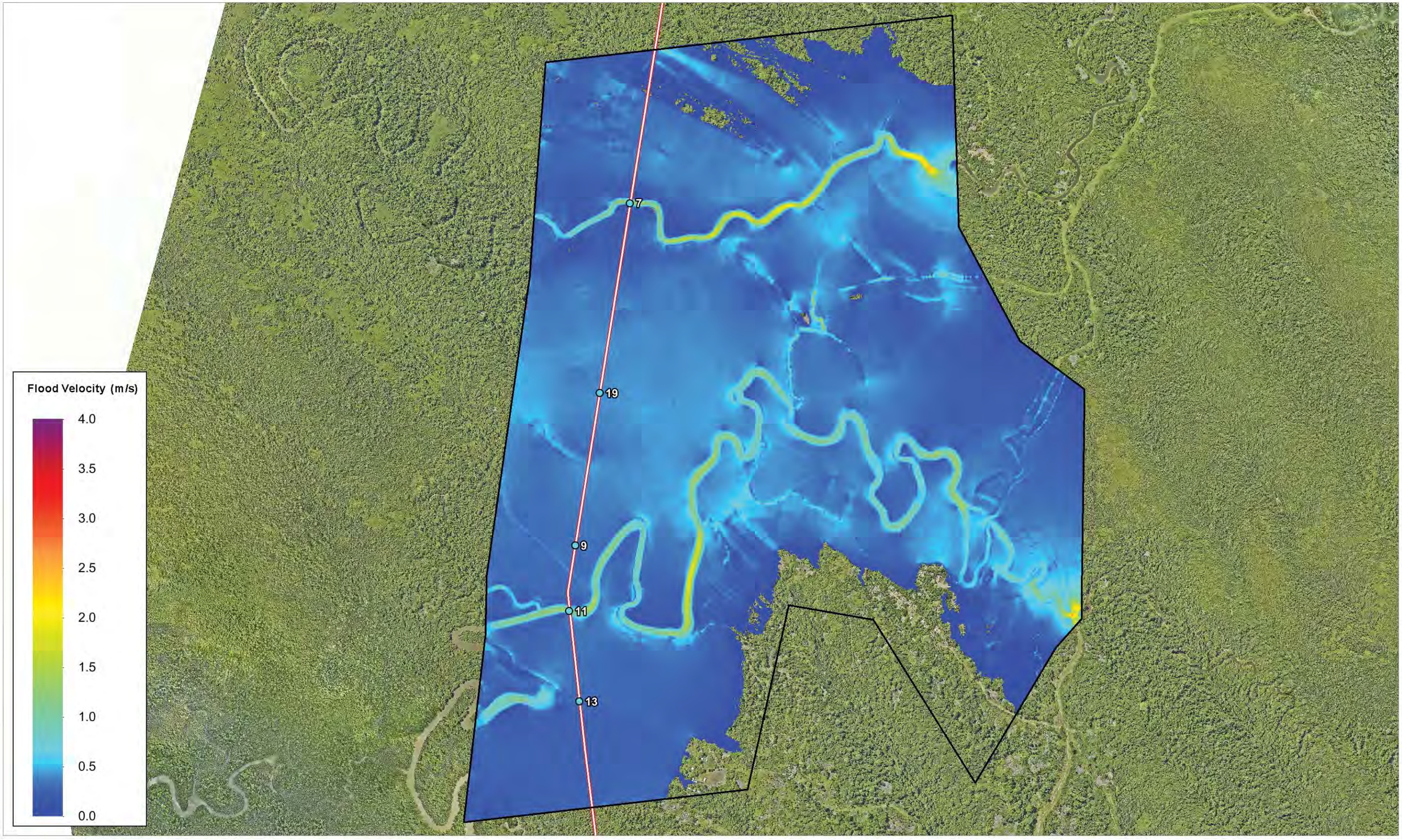
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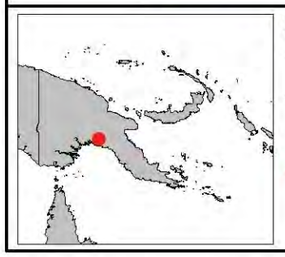
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S20 Flood Velocity - 50 year event

Figure: D-94

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 500 1,000m

Approx. Scale

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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_100_170317_S20_v_50y.wor

Flood Level (m)

8
7
6
5
4
3
2
1
0

7
19
9
11
13

LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:
Model S20 Flood Levels - 100 year event

Figure: D-95

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

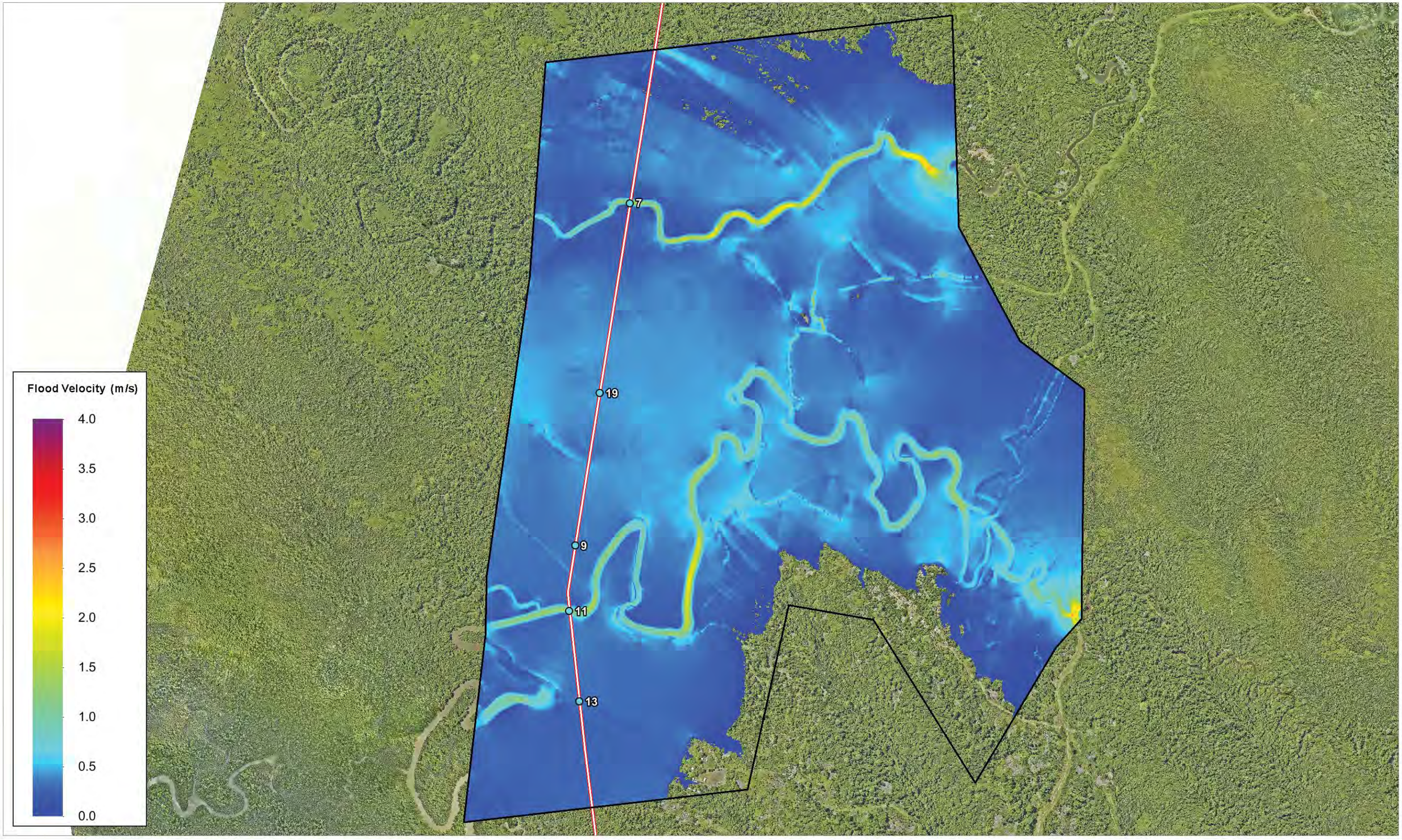
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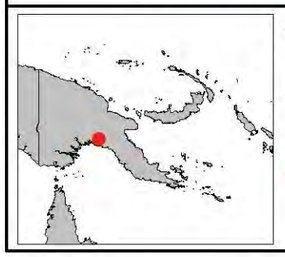
0 500 1,000m

Approx. Scale

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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_101_170317_S20_h_100y.wor





LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S20 Flood Velocity - 100 year event

Figure: D-96

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

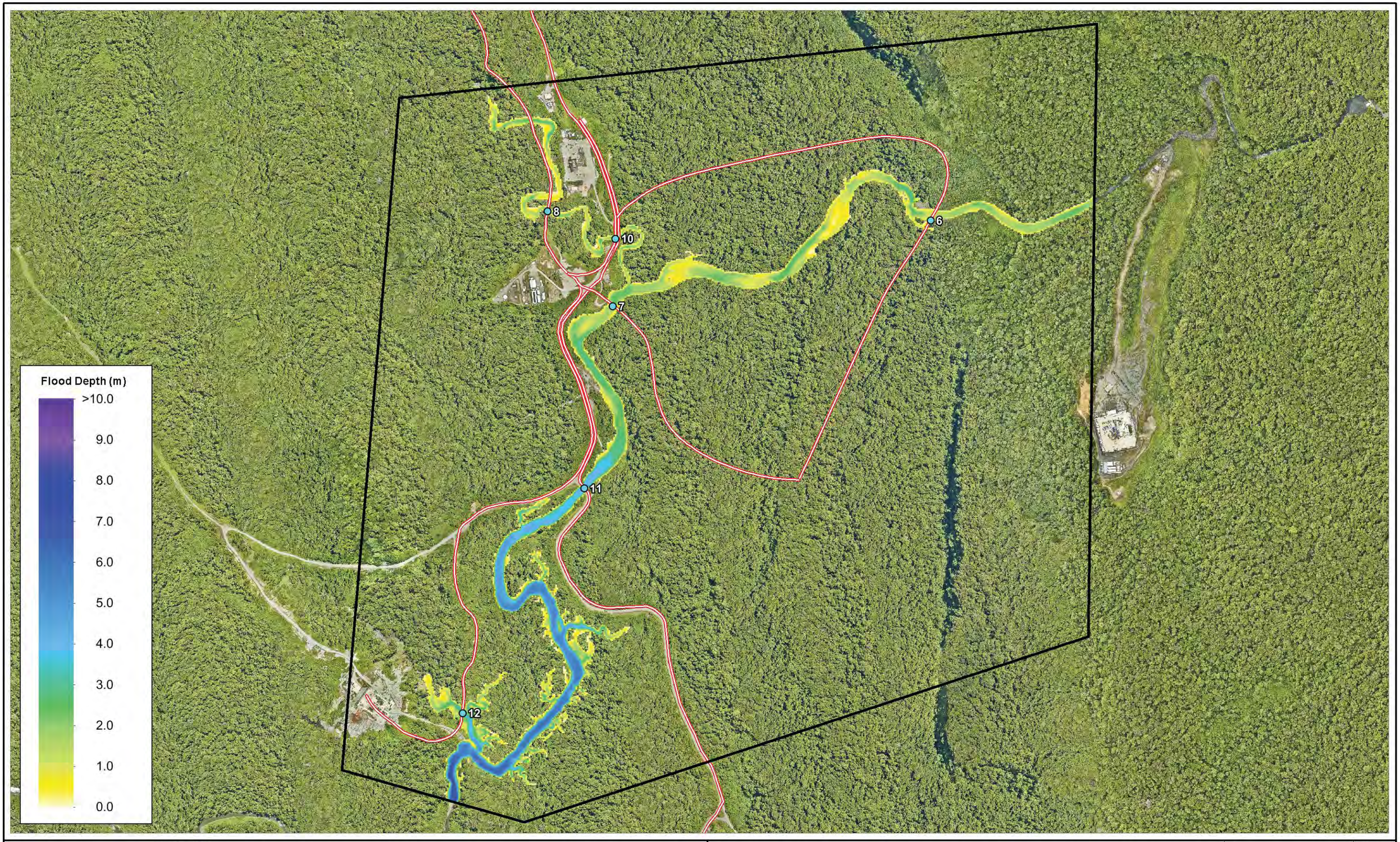
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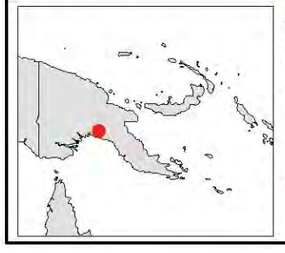
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S1 Flood Depth - 10 year event

Figure: D-97

Rev: A

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N

0 250 500m

Approx. Scale

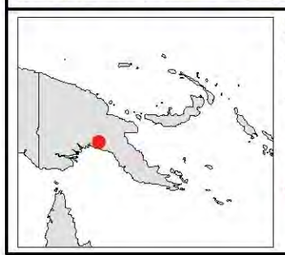
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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_103_170718_S1_d_10y.wor

Flood Depth (m)
>10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0

8
10
6
7
11
12



LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:
Model S1 Flood Depth - 50 year event

Figure: D-98

Rev: A

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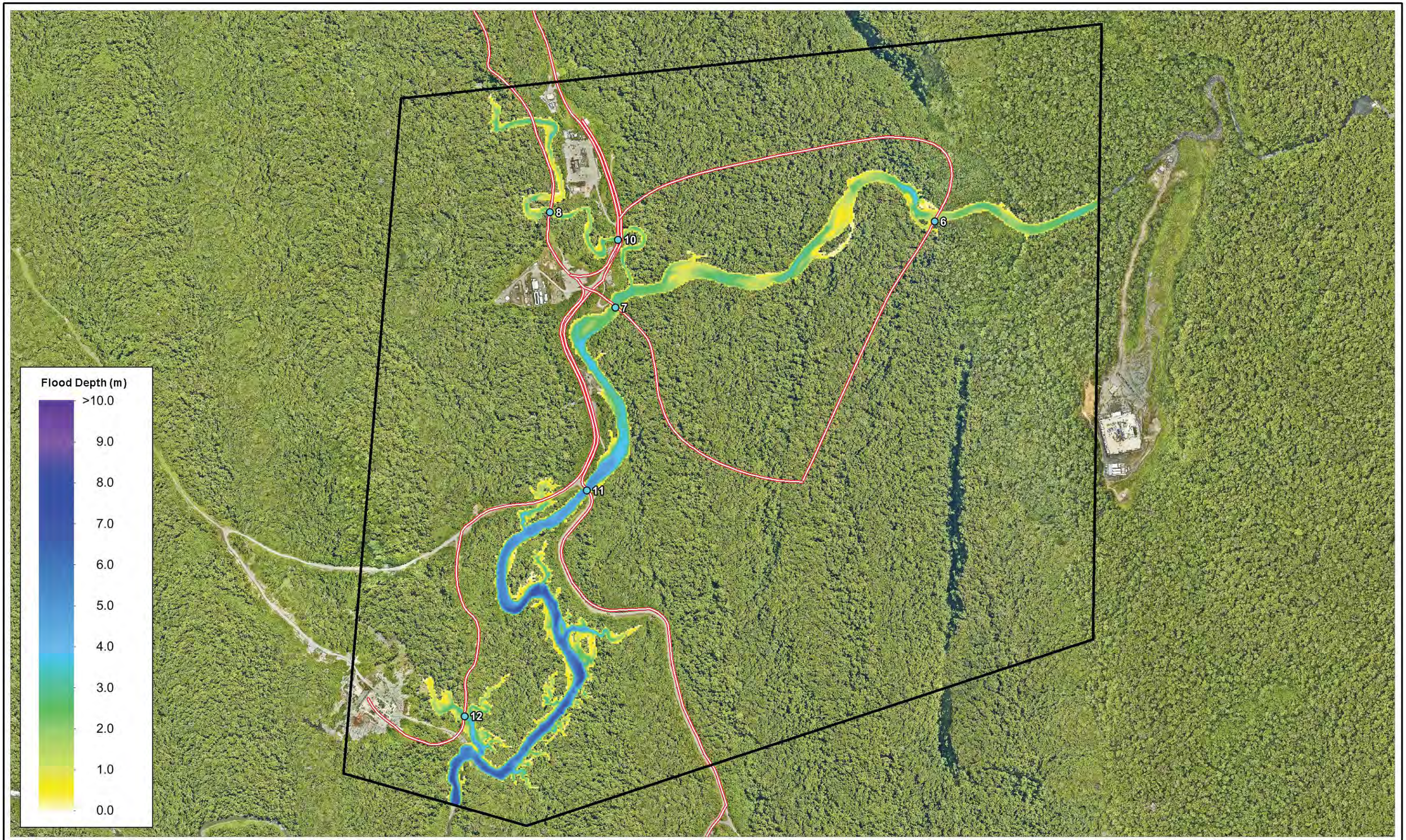
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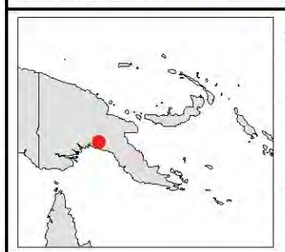
0 250 500m

Approx. Scale

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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_104_170718_S1_d_50y.wor





LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S1 Flood Depth - 100 year event

Figure: D-99

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

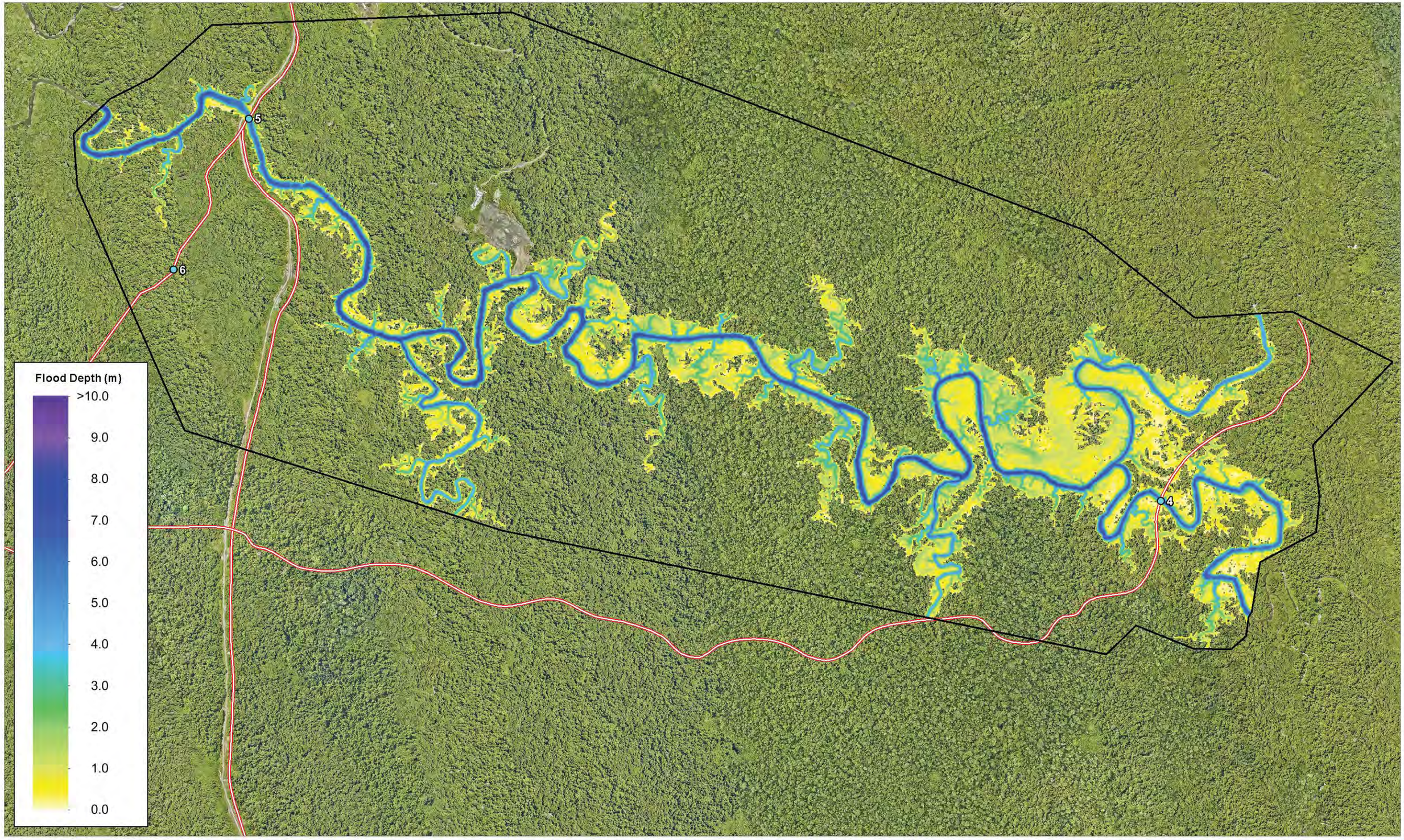
0 250 500m

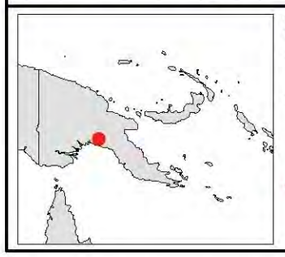
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S2 Flood Depth - 10 year event

Figure: D-100

Rev: A

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N

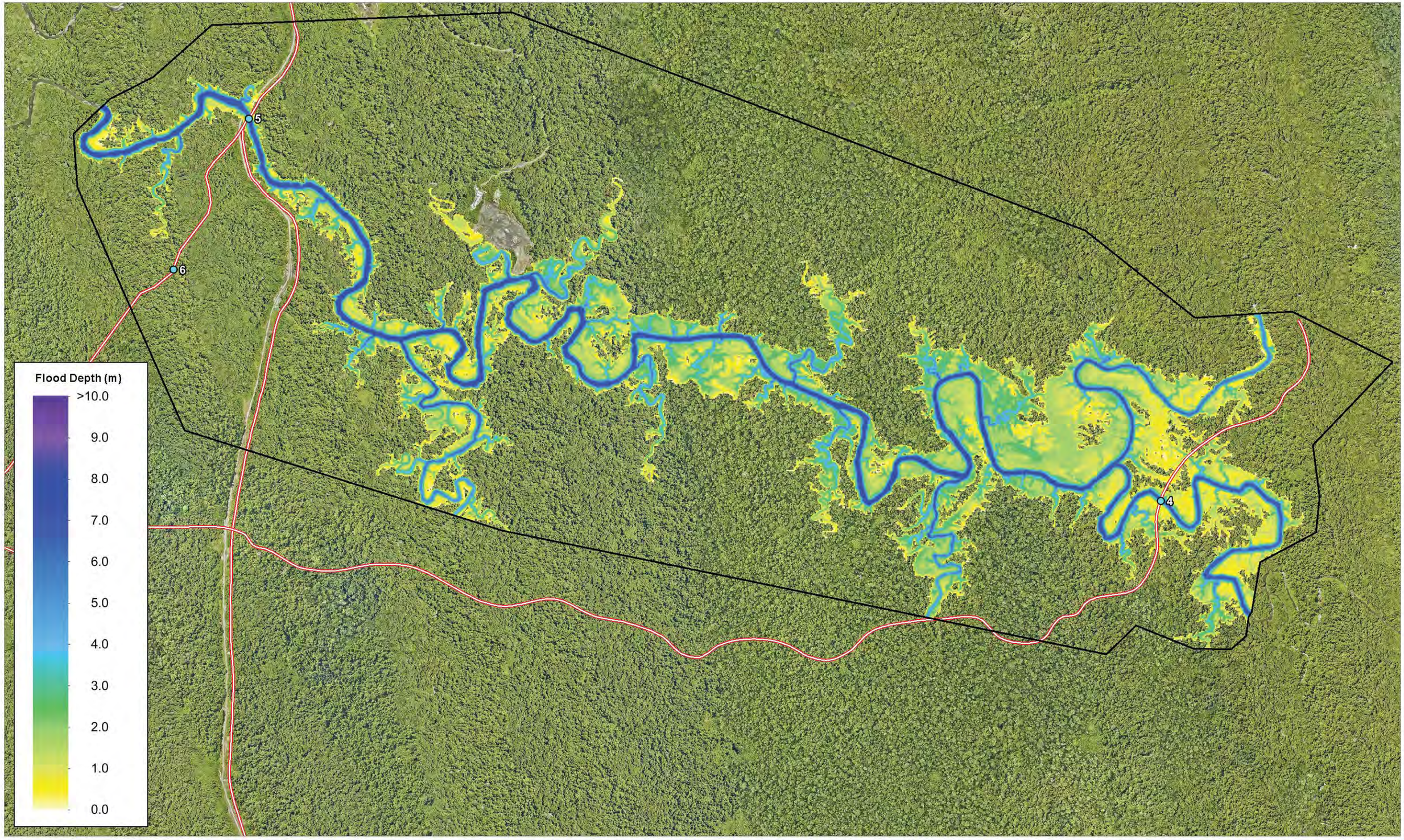
0 250 500m

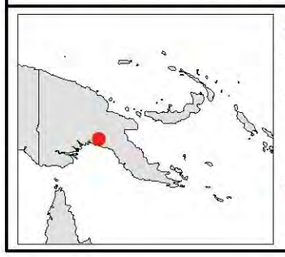
Approx. Scale

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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_106_170718_S2_d_10y.wor





LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S2 Flood Depth - 50 year event

Figure: D-101

Rev: A

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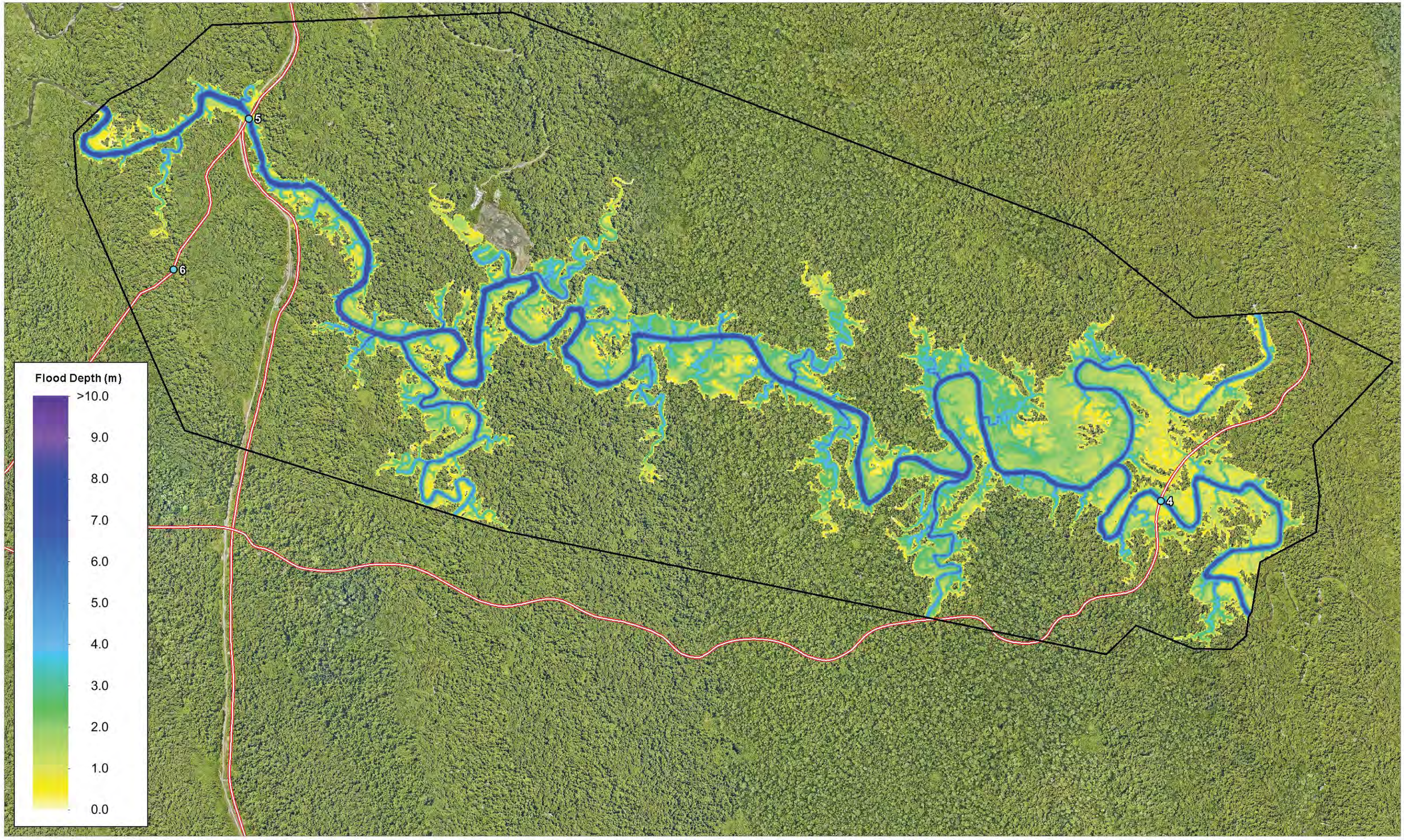
0 250 500m

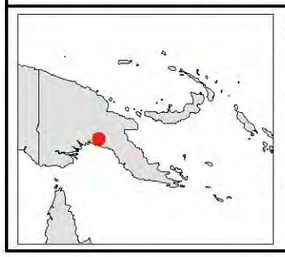
Approx. Scale

BMT WBM

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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_107_170718_S2_d_50y.wor





LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S2 Flood Depth - 100 year event

Figure: D-102

Rev: A

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N

0 250 500m

Approx. Scale

BMT WBM

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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_108_170718_S2_d_100y.wor

Flood Depth (m)
>10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0

8
6
7
5
4

LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:
Model S4 Flood Depth - 10 year event

Figure: D-103

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 250 500m

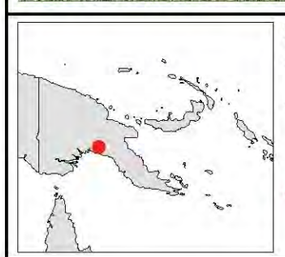
Approx. Scale

BMT WBM
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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_109_170718_S4_d_10y.wor

Flood Depth (m)
>10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0

8
6
7
5
4



LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:
Model S4 Flood Depth - 50 year event

Figure: D-104

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

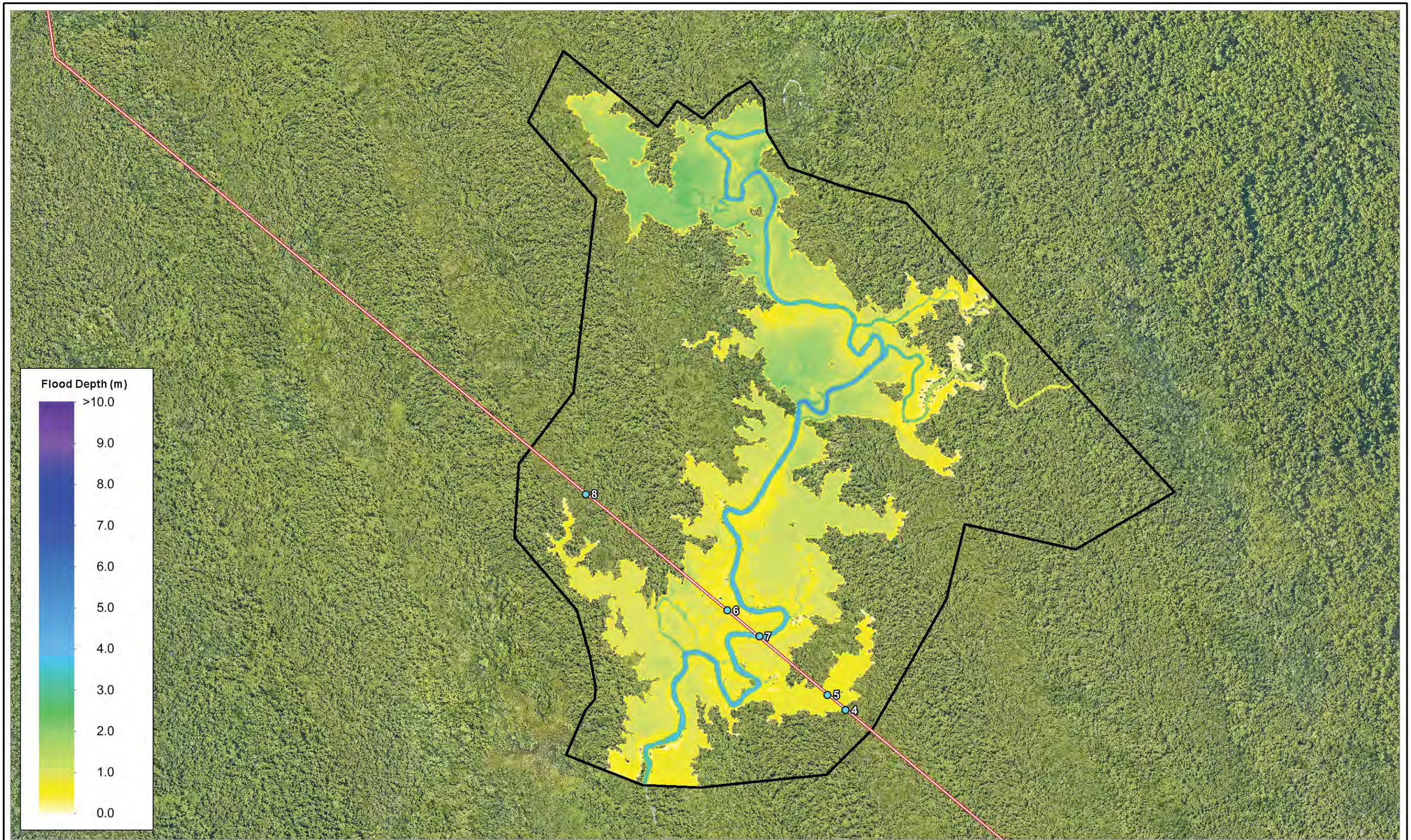
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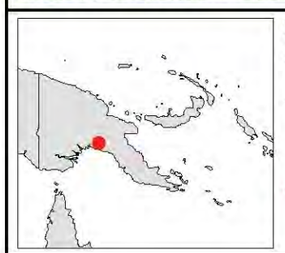
0 250 500m

Approx. Scale

BMT WBM
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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_110_170718_S4_d_50y.wor





LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S4 Flood Depth - 100 year event

Figure: D-105

Rev: A

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N

0 250 500m

Approx. Scale

BMT WBM

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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_111_170718_S4_d_100y.wor

Flood Depth (m)

>10.0

9.0

8.0

7.0

6.0

5.0

4.0

3.0

2.0

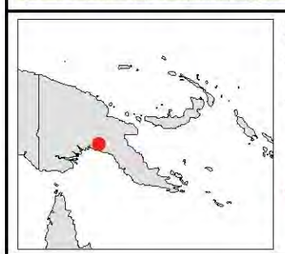
1.0

0.0

8

7

6



LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S5 Flood Depth - 10 year event

Figure: D-106

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 250 500m

Approx. Scale

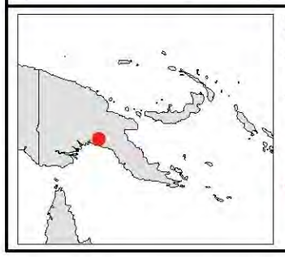
BMT WBM

www.bmtwbm.com.au

Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_112_170718_S5_d_10y.wor

Flood Depth (m)
>10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0

8
7
6



LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:
Model S5 Flood Depth - 50 year event

Figure: D-107

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

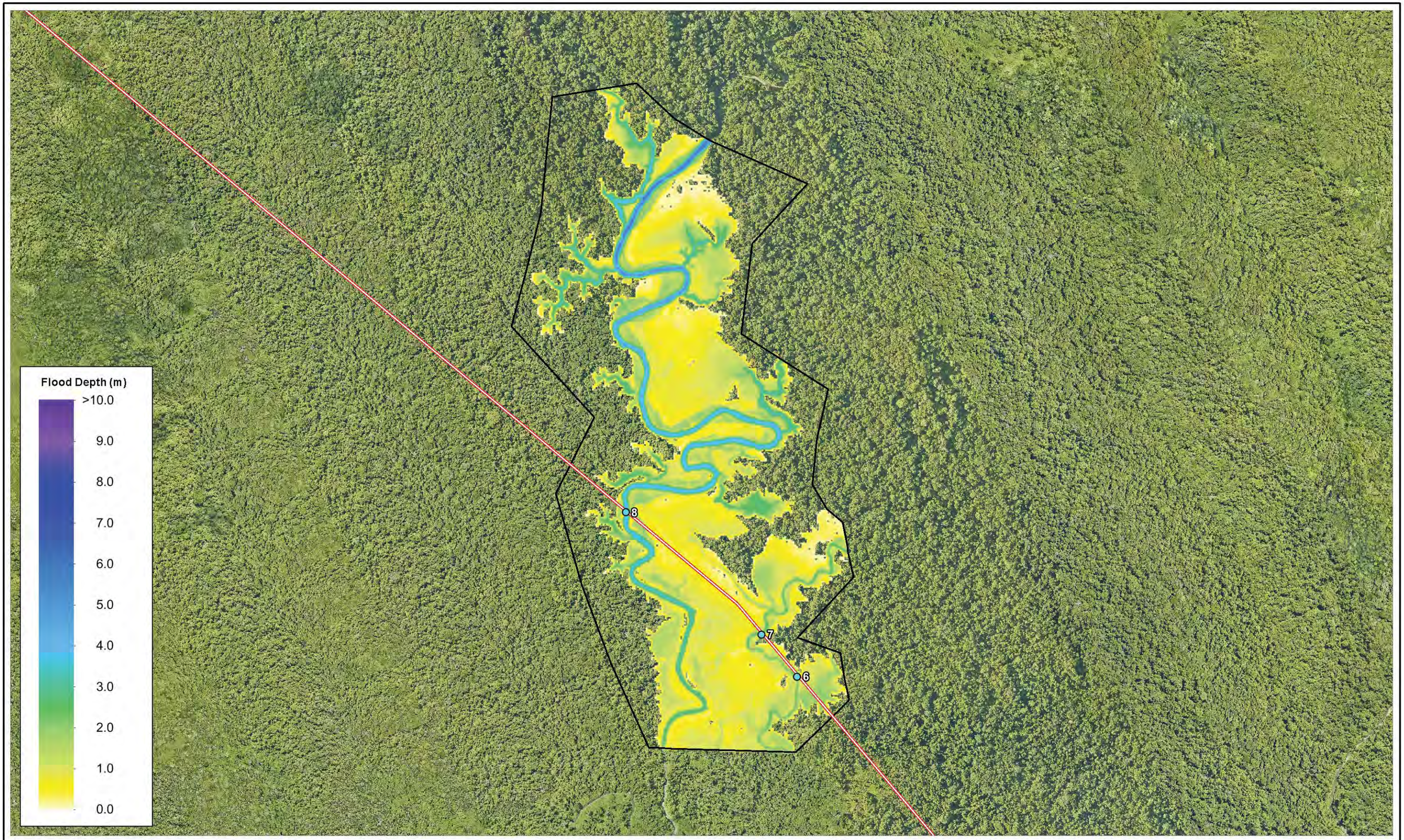
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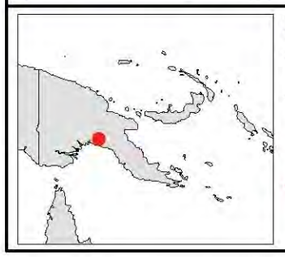
0 250 500m

Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_113_170718_S5_d_50y.wor





LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S5 Flood Depth - 100 year event

Figure: D-108

Rev: A

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N

0 250 500m

Approx. Scale

BMT WBM
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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_114_170718_S5_d_100y.wor

Flood Depth (m)
>10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0

5
6

LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:
Model S6 Flood Depth - 10 year event

Figure: D-109

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

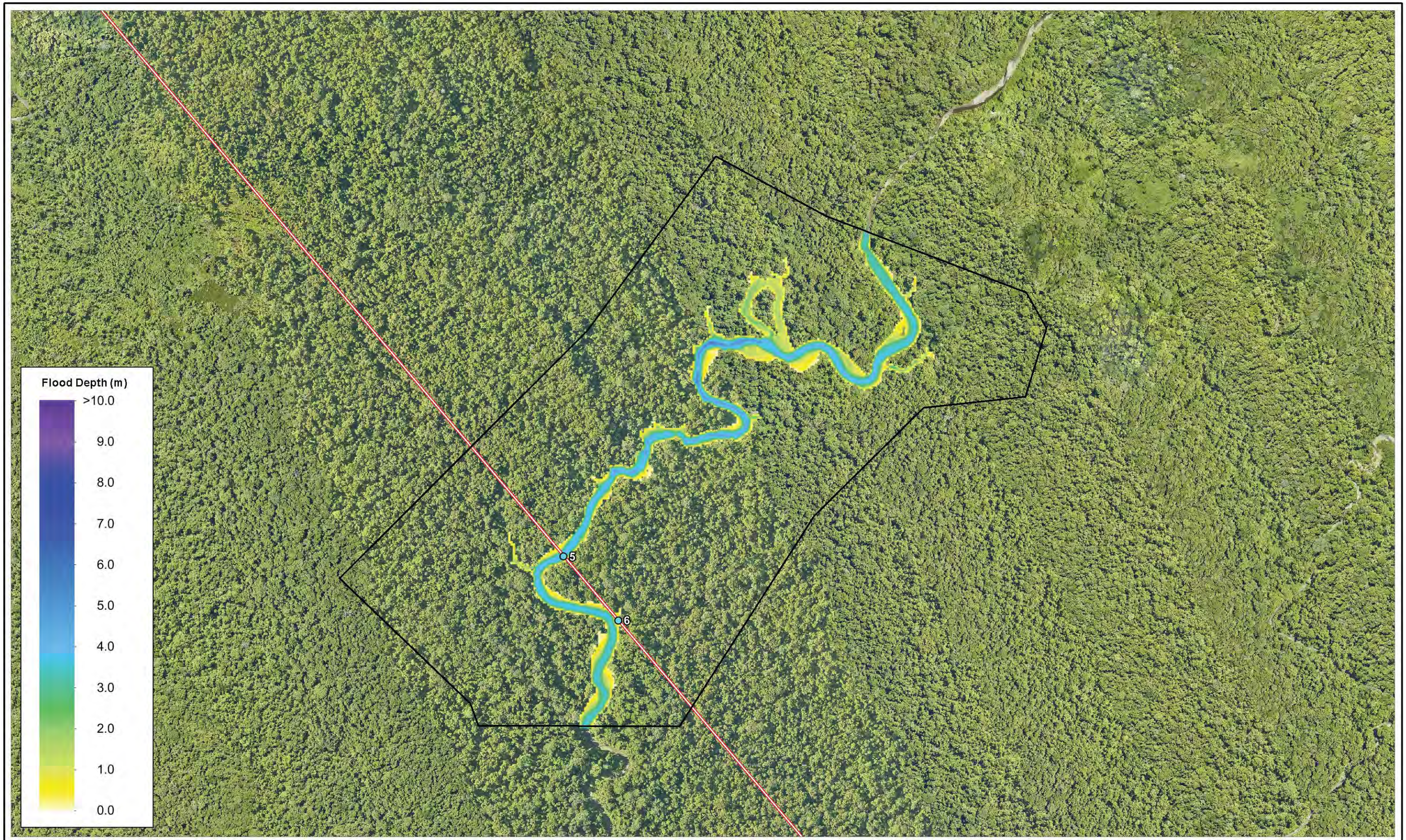
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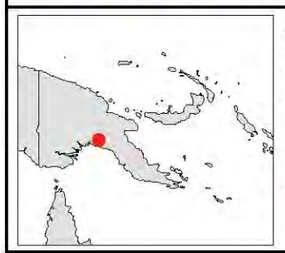
0 200 400m

Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_115_170718_S6_d_10y.wor





LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S6 Flood Depth - 50 year event

Figure: D-110

Rev: A

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N

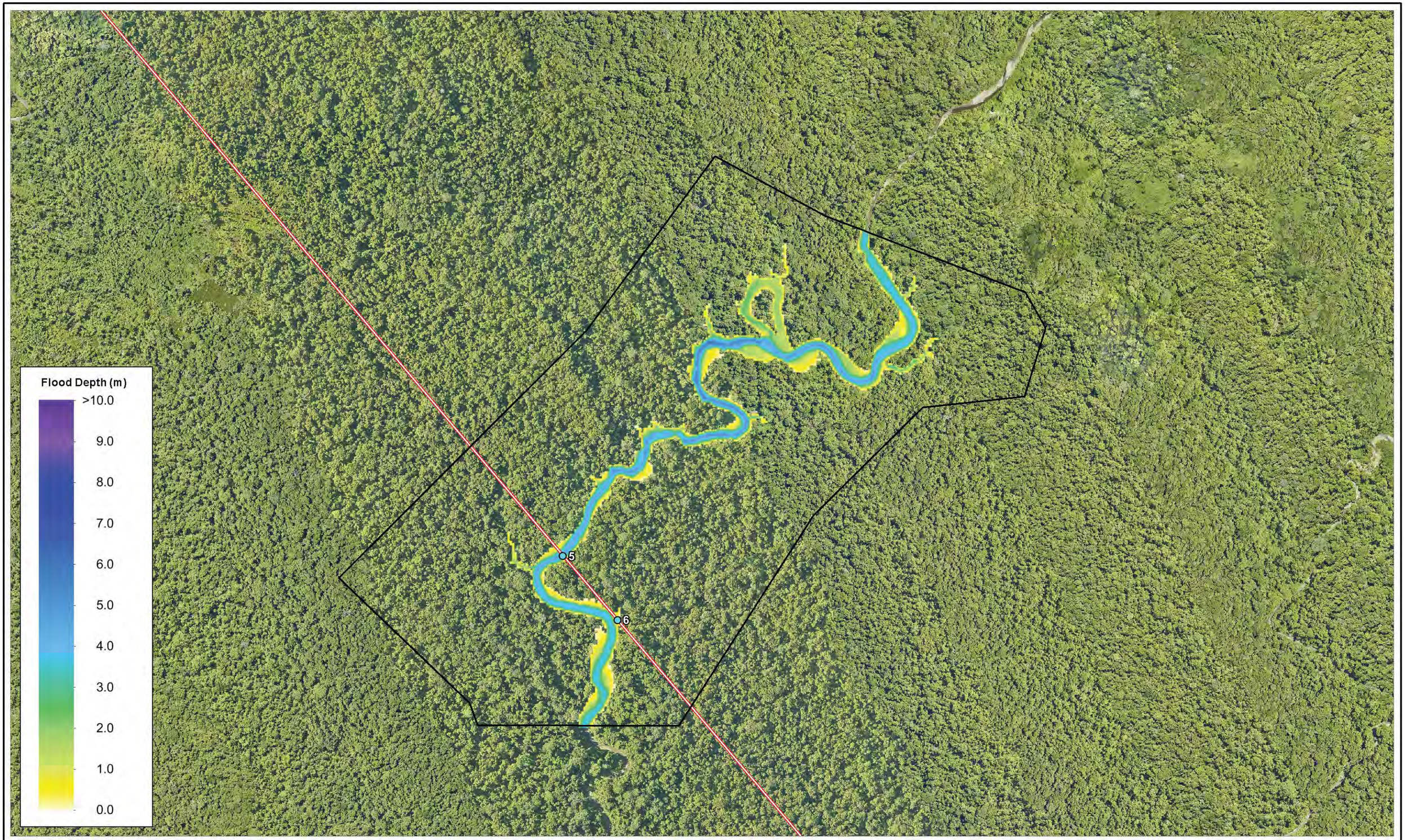
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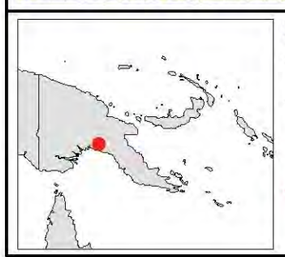
Approx. Scale

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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S6 Flood Depth - 100 year event

Figure: D-111

Rev: A

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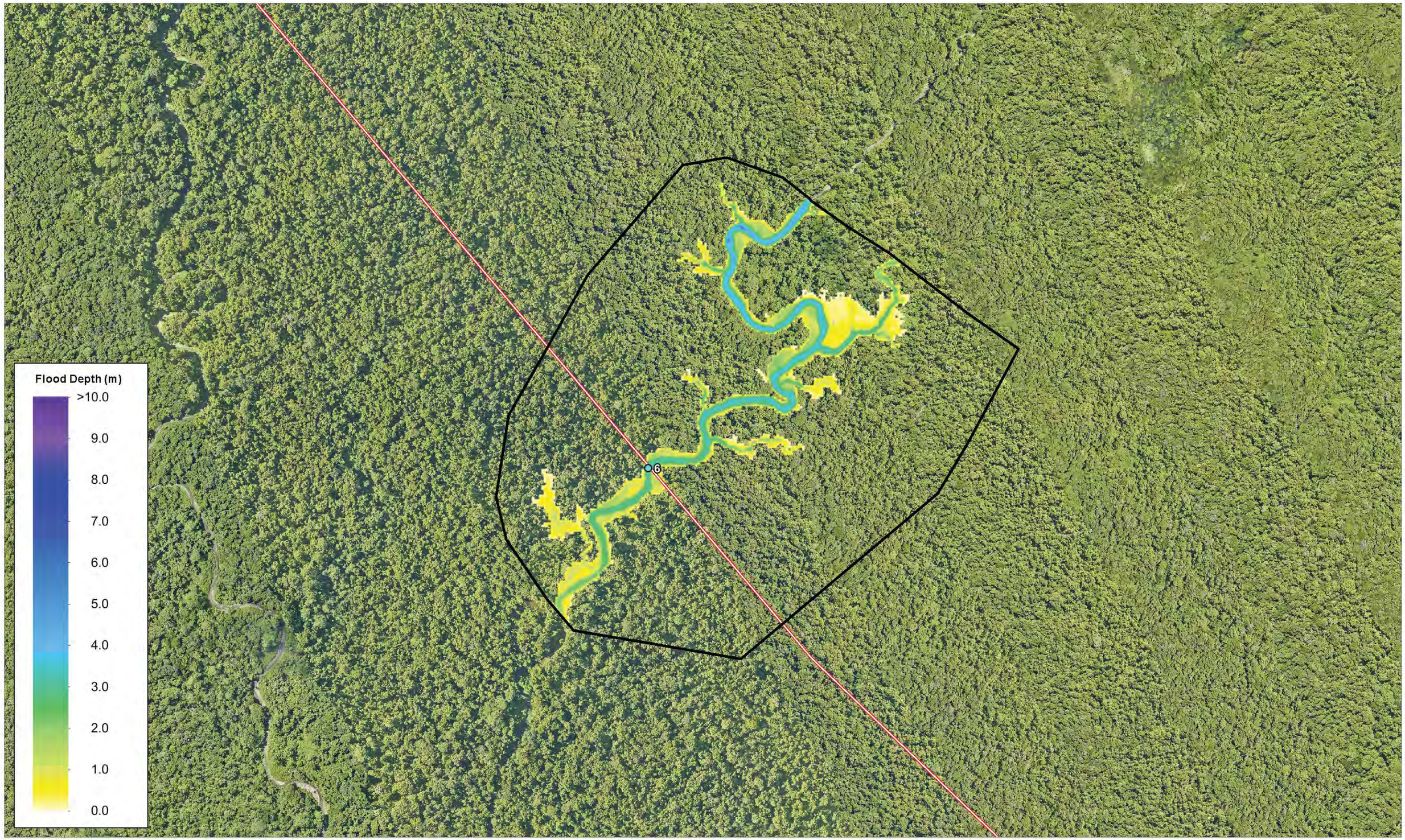
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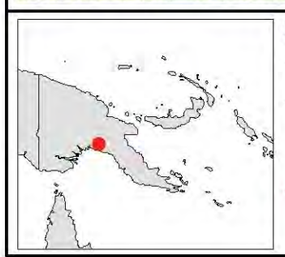
Approx. Scale

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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_117_170718_S6_d_100y.wor





LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S7 Flood Depth - 10 year event

Figure: D-112

Rev: A

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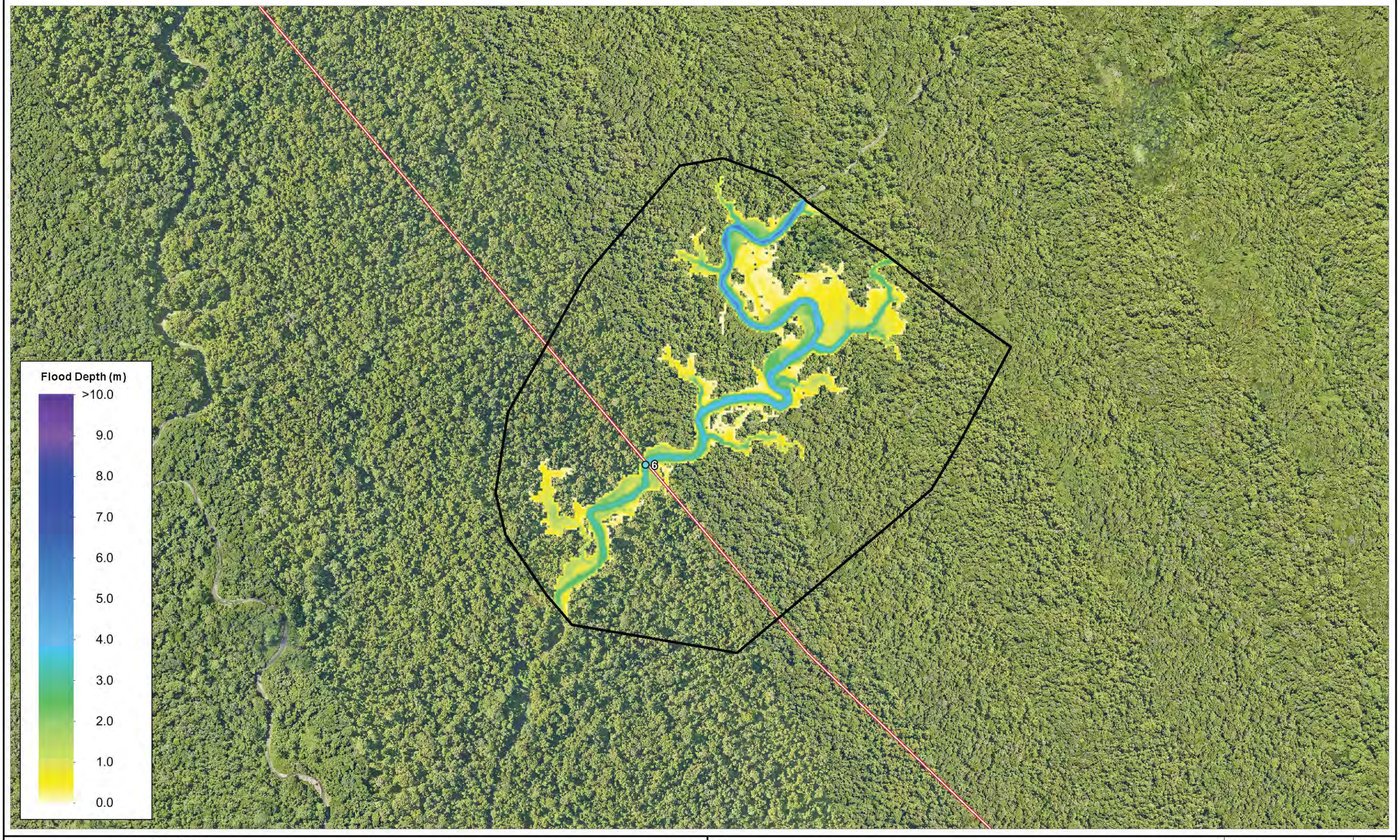
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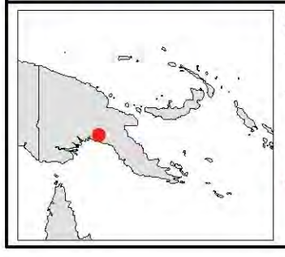
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S7 Flood Depth - 50 year event

Figure: D-113

Rev: A

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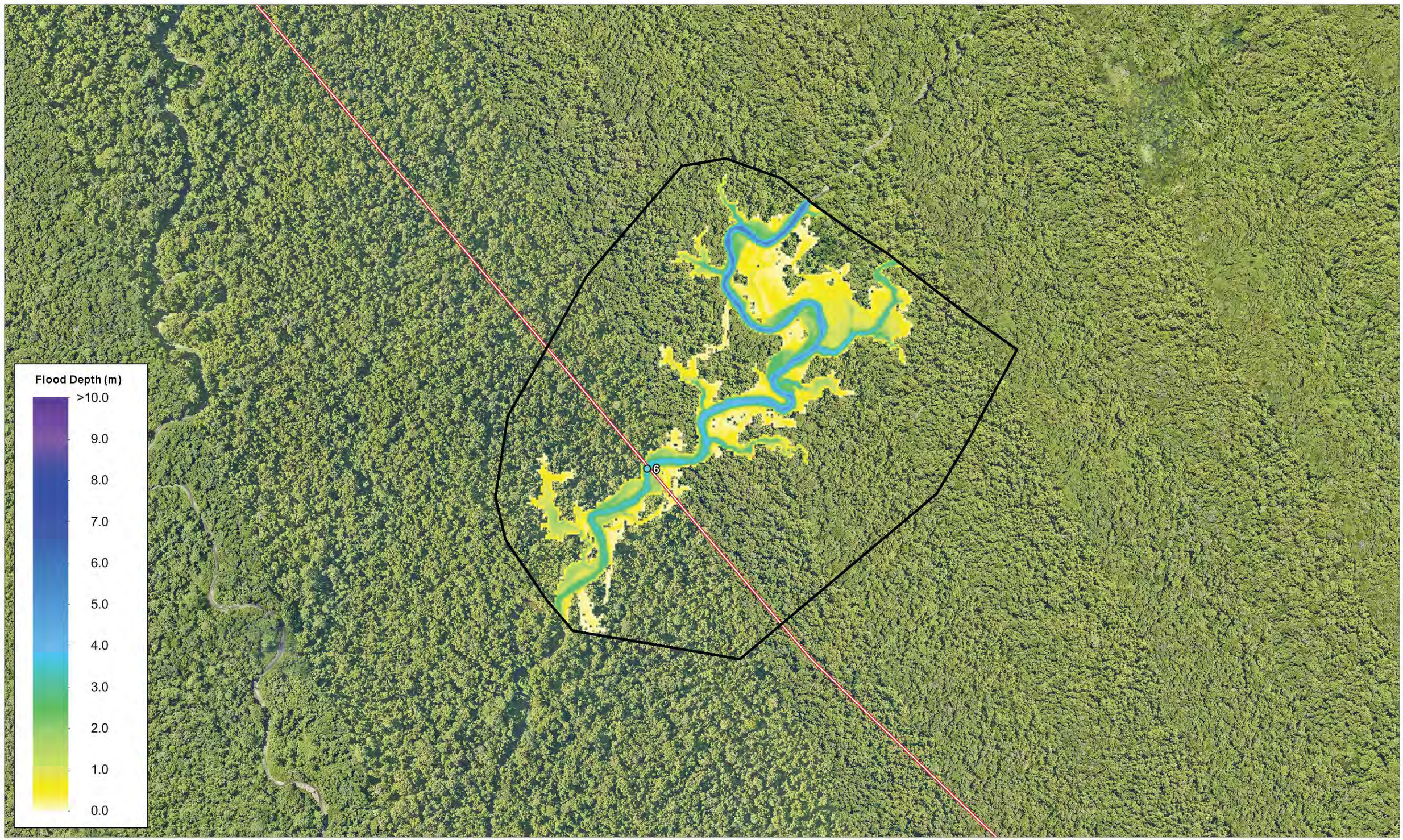
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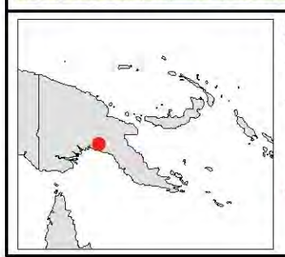
Approx. Scale

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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S7 Flood Depth - 100 year event

Figure: D-114

Rev: A

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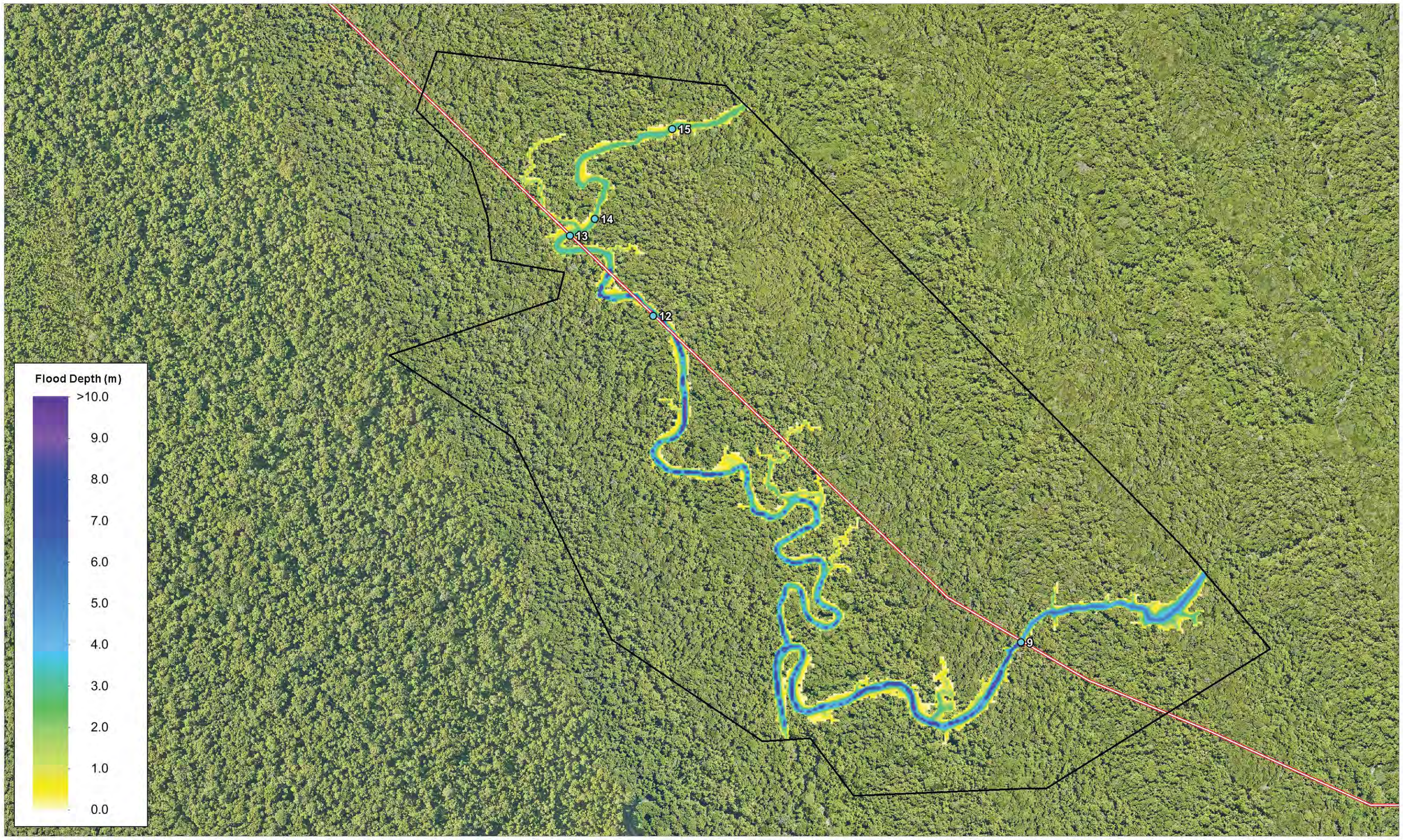
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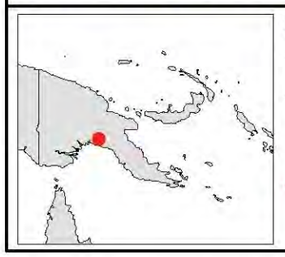
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S8 Flood Depth - 10 year event

Figure: D-115

Rev: A

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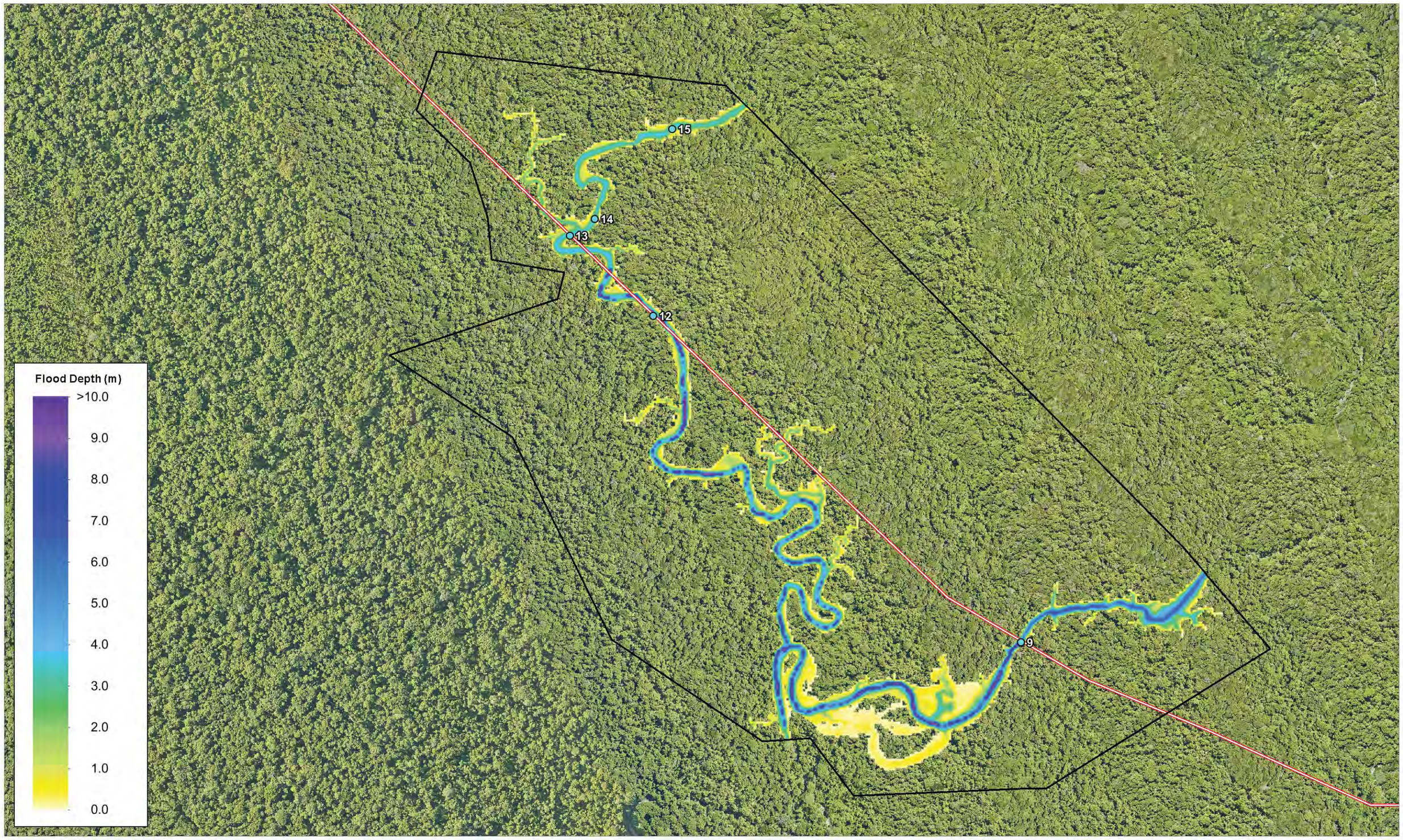
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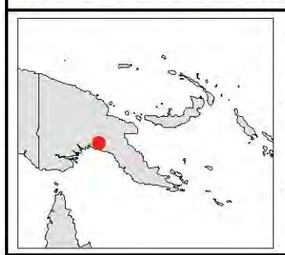
Approx. Scale

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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S8 Flood Depth - 50 year event

Figure: D-116

Rev: A

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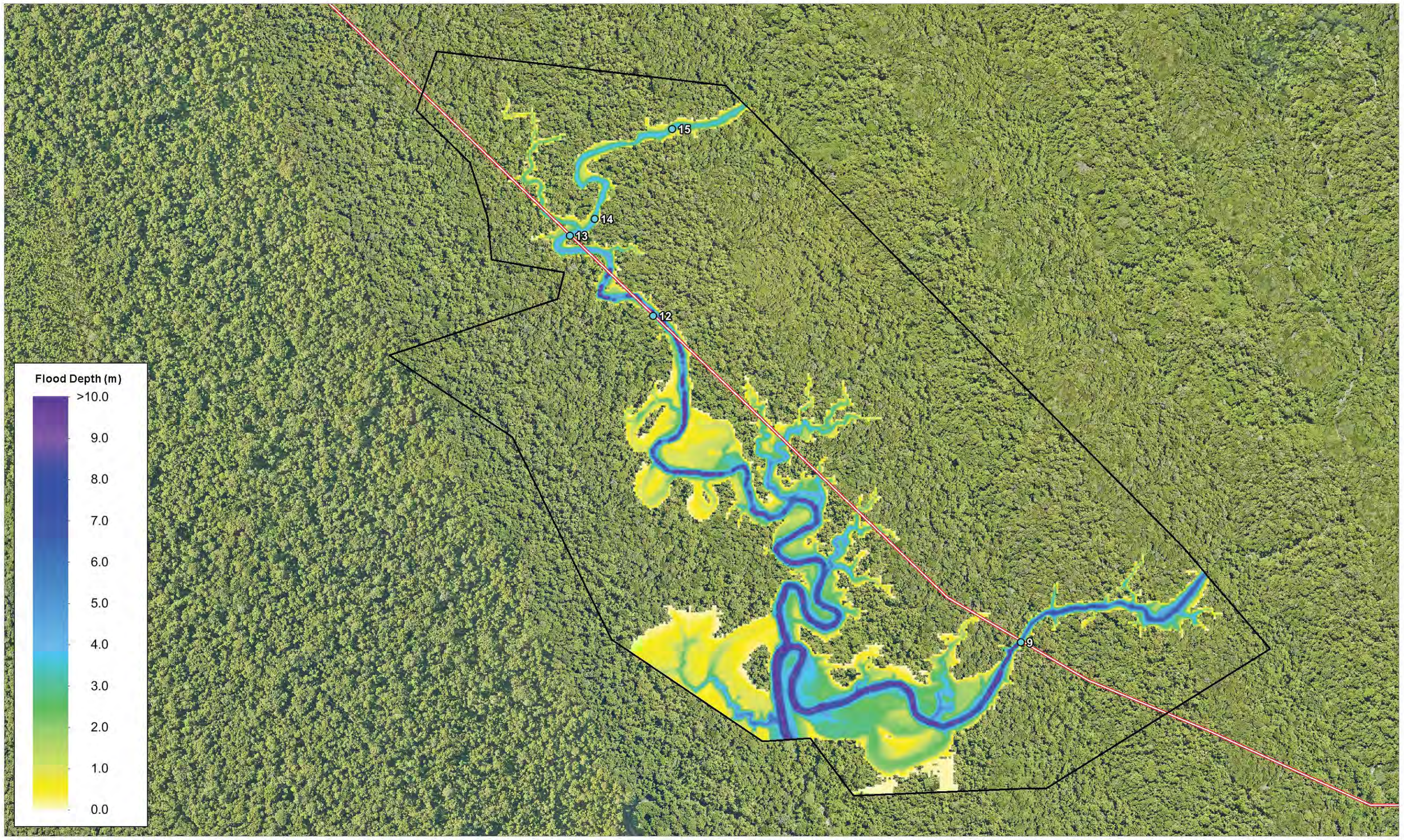
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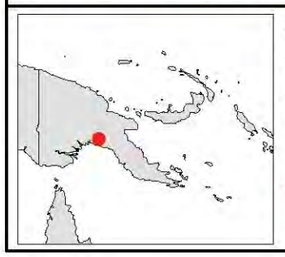
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S8 Flood Depth - 100 year event

Figure: D-117

Rev: A

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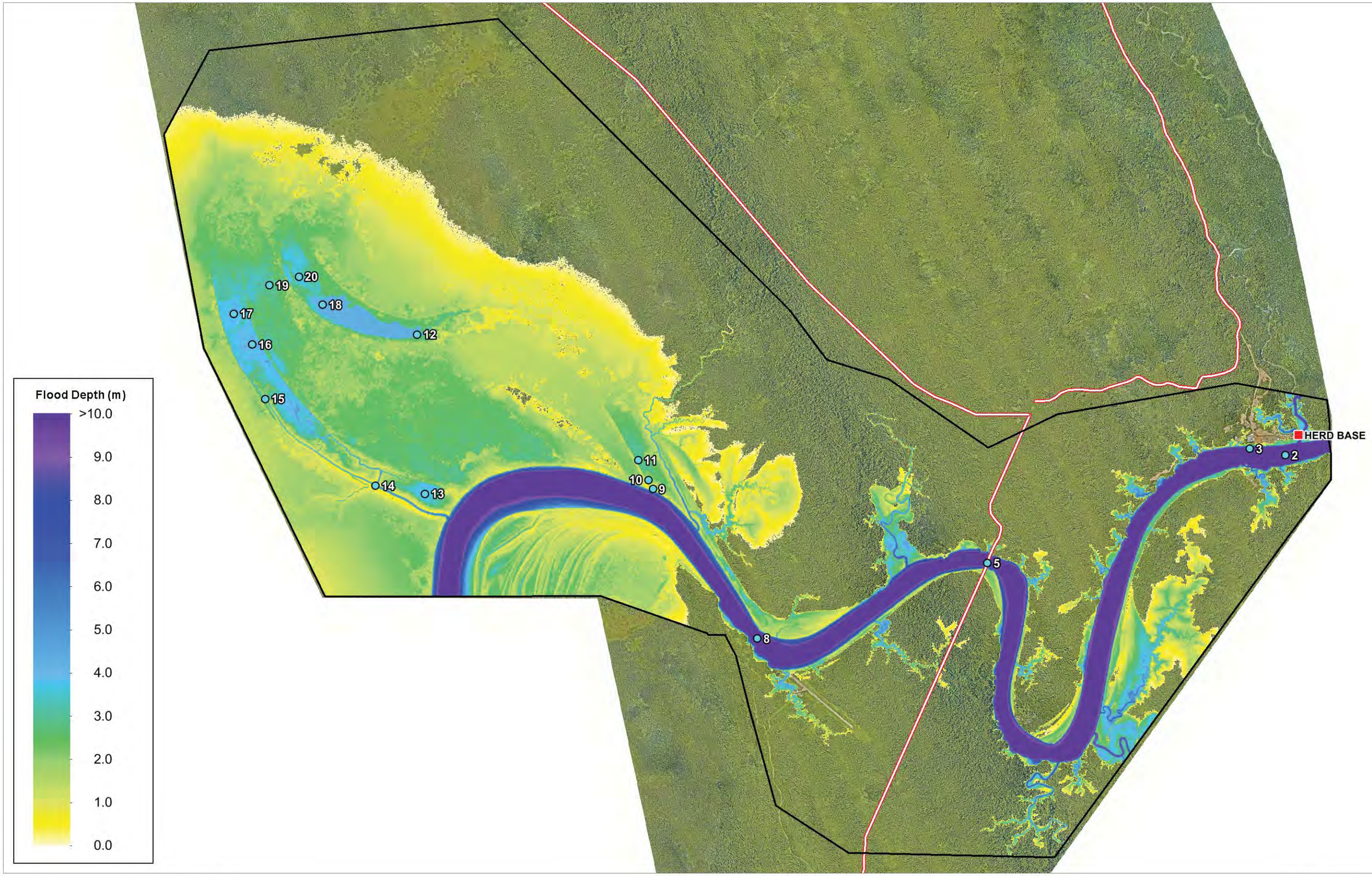
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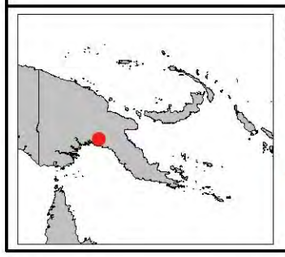
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option
- Herd Base

Title:

Model S10 Flood Depth - 10 year event

Figure: D-118

Rev: A

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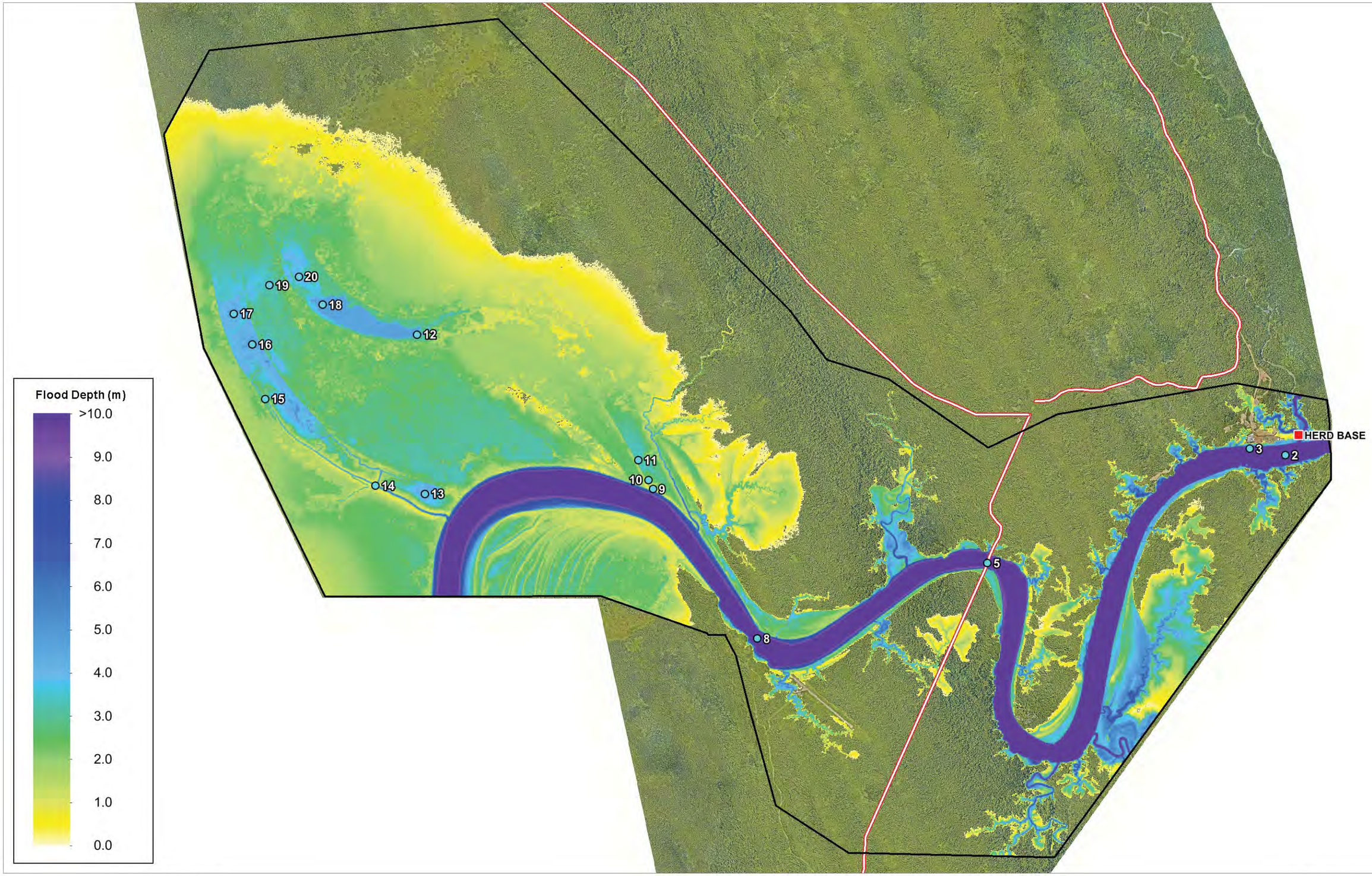
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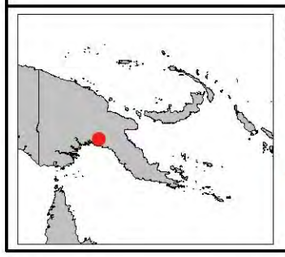
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option
- Herd Base

Title:

Model S10 Flood Depth - 50 year event

Figure: D-119

Rev: A

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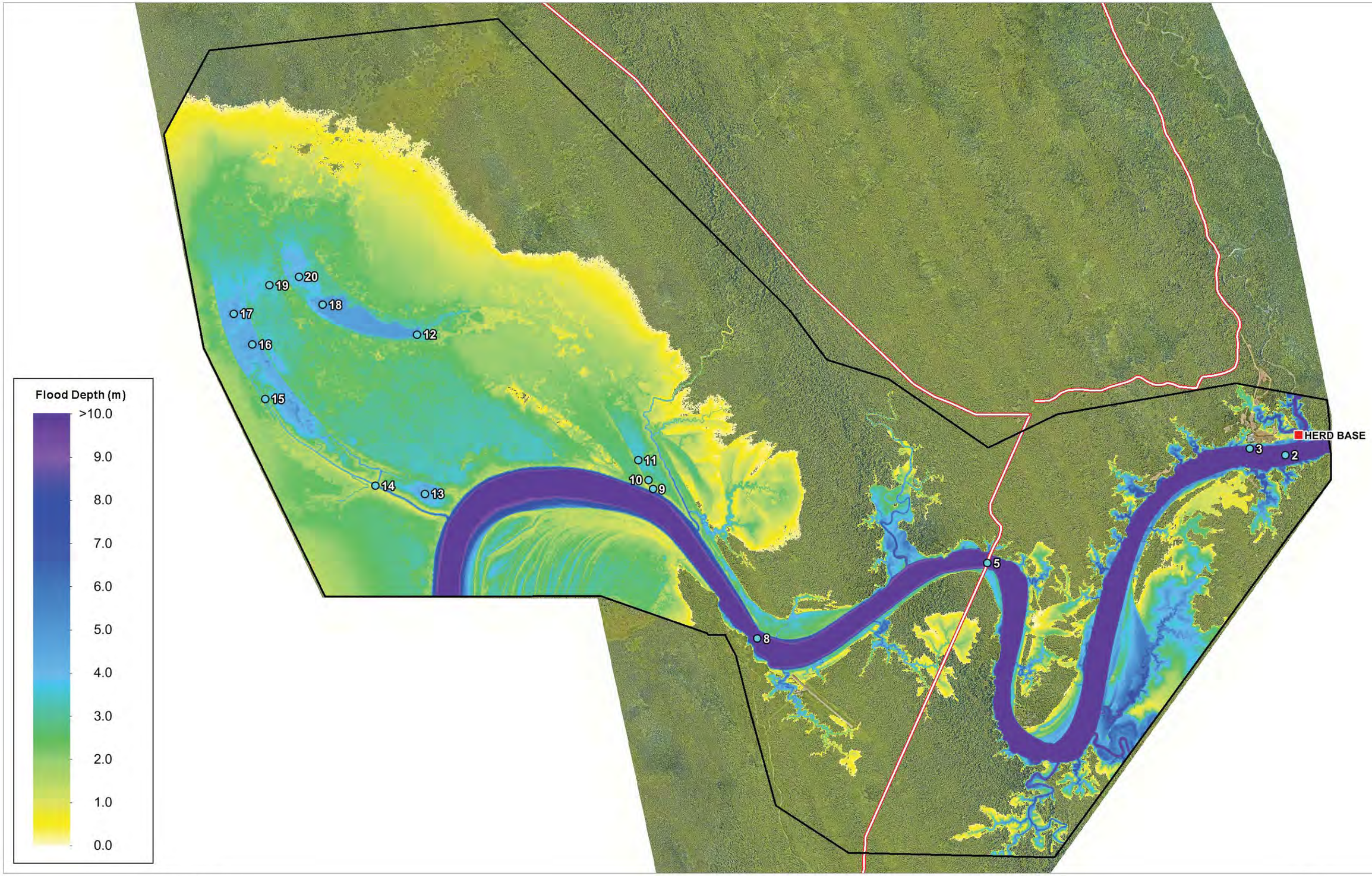
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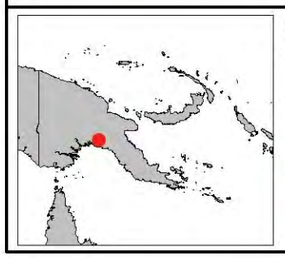
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option
- Herd Base

Title:

Model S10 Flood Depth - 100 year event

Figure: D-120

Rev: A

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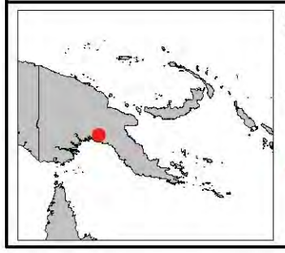
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S11 Flood Depth - 10 year event

Figure: D-121

Rev: A

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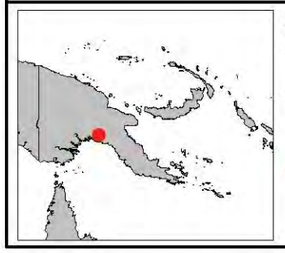
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Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S11 Flood Depth - 50 year event

Figure: D-122

Rev: A

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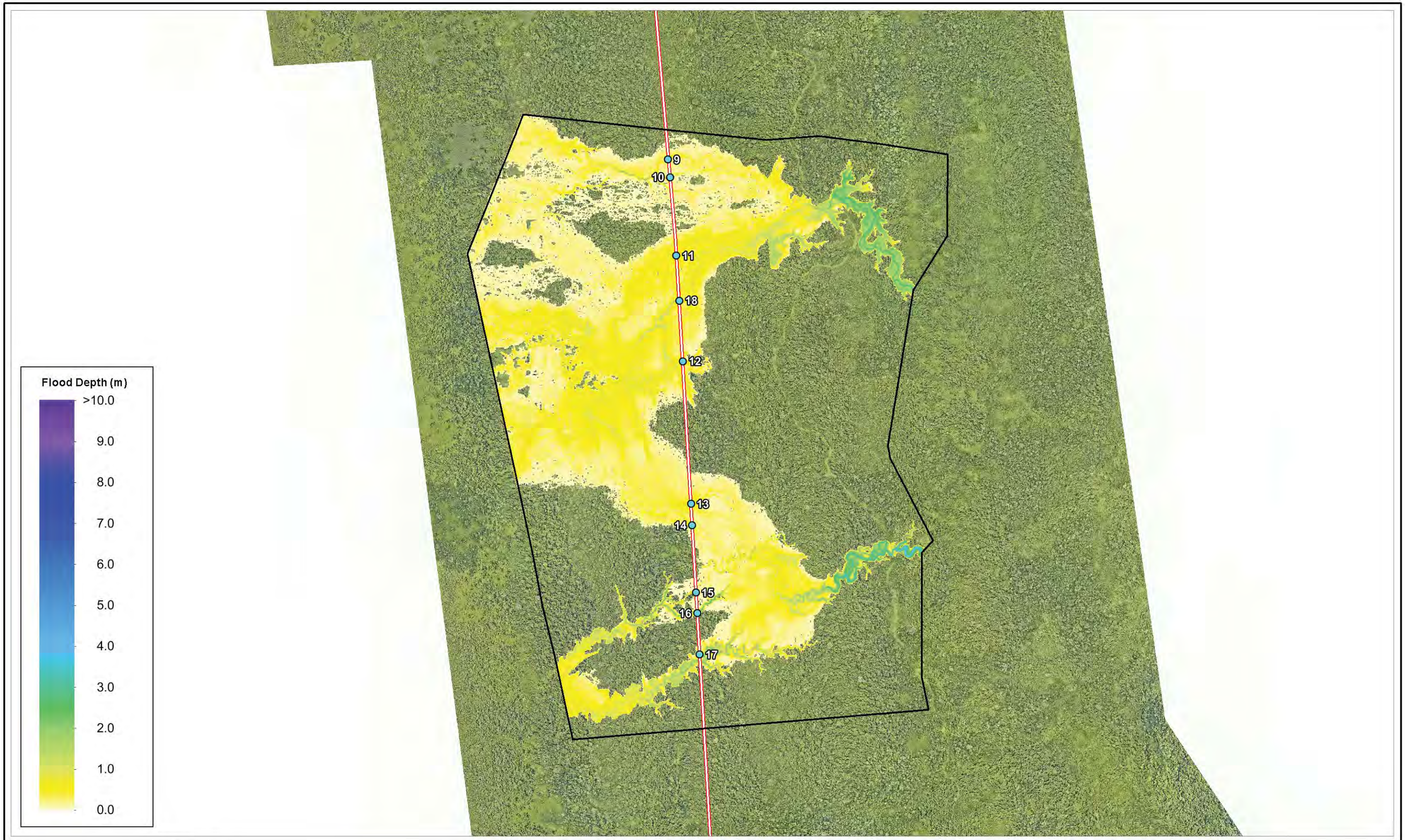
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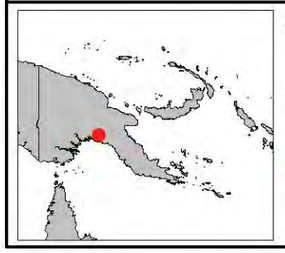
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S11 Flood Depth - 100 year event

Figure: D-123

Rev: A

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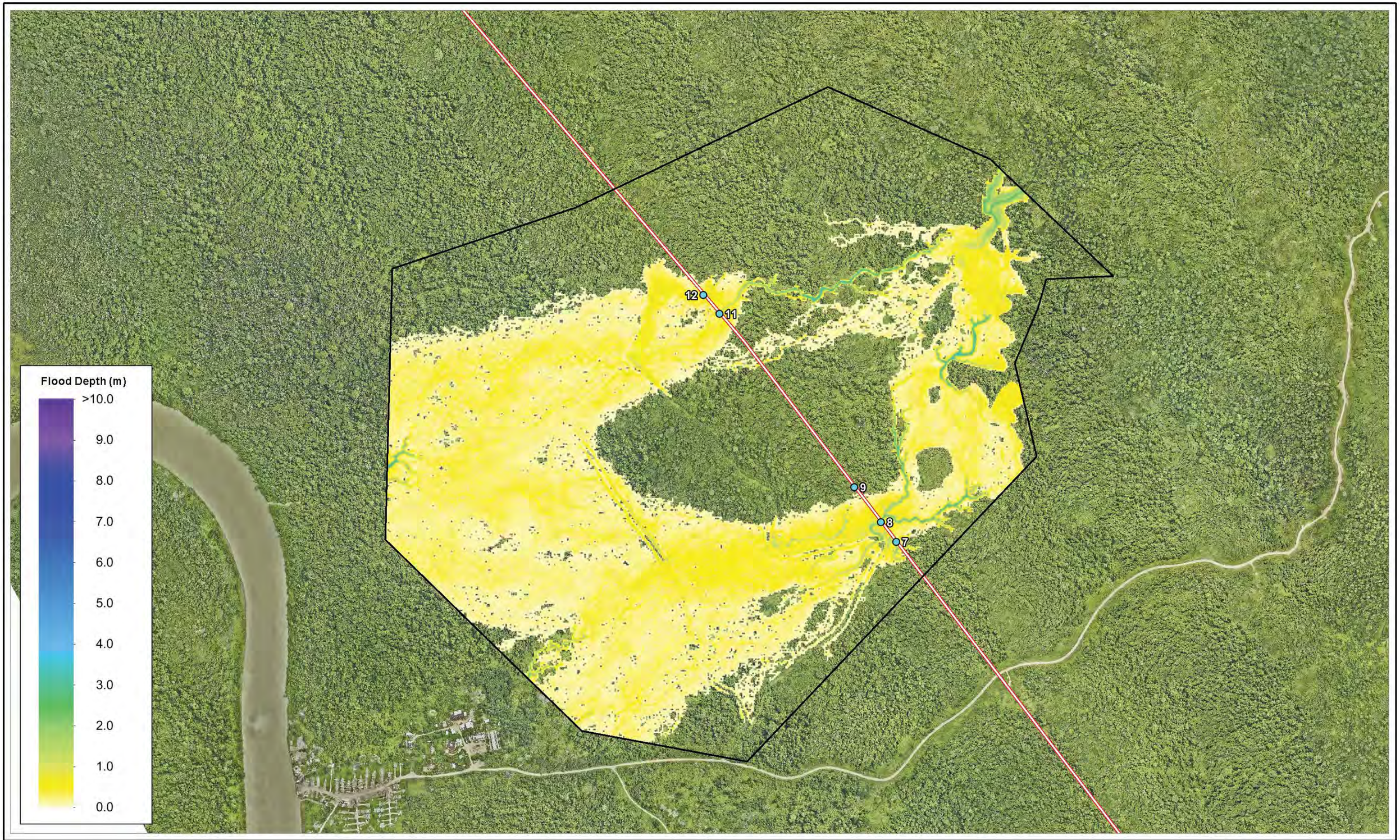
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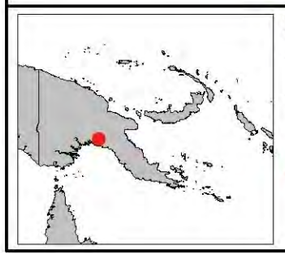
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:
Model S12 Flood Depth - 10 year event

Figure: D-124

Rev: A

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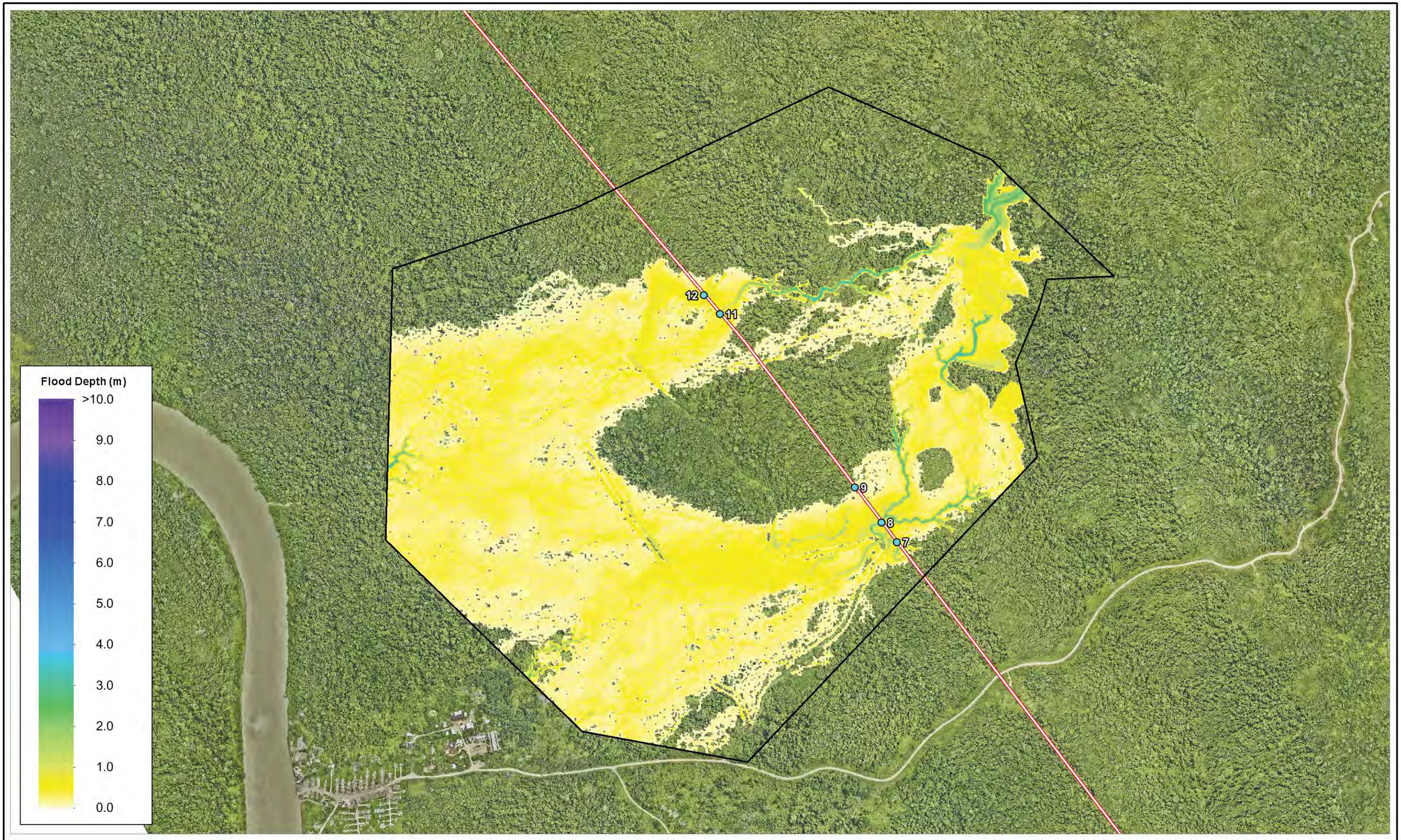
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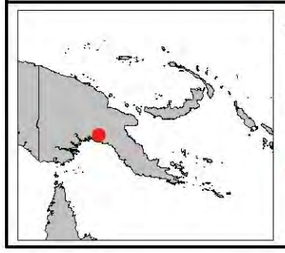
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Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S12 Flood Depth - 50 year event

Figure: D-125

Rev: A

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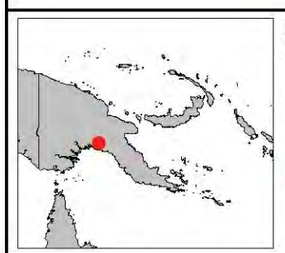
Approx. Scale

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LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S13 Flood Depth - 10 year event

Figure: D-127

Rev: A

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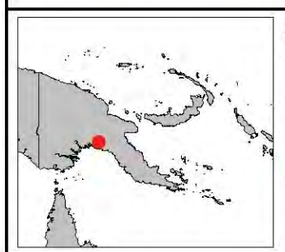
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S13 Flood Depth - 50 year event

Figure: D-128

Rev: A

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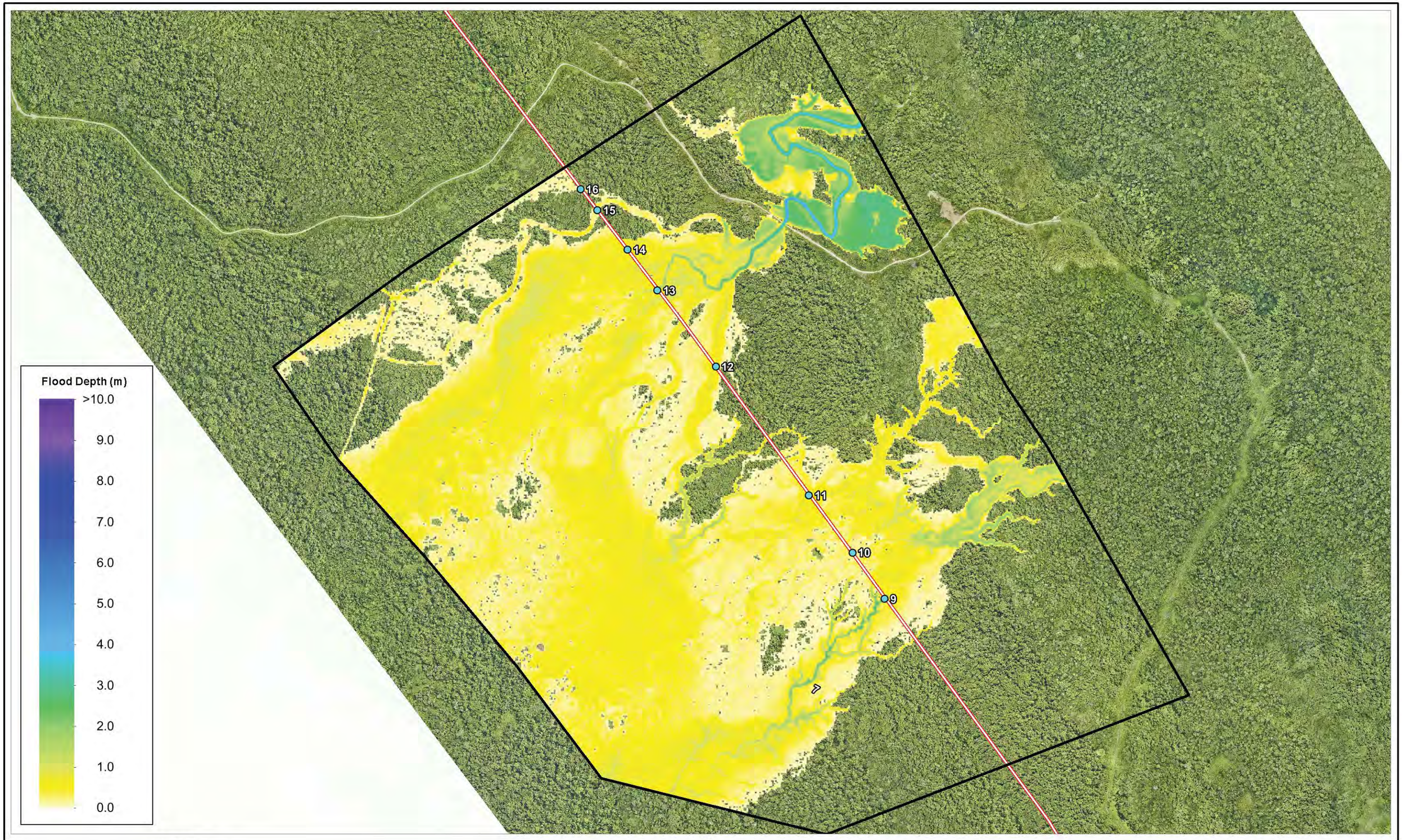
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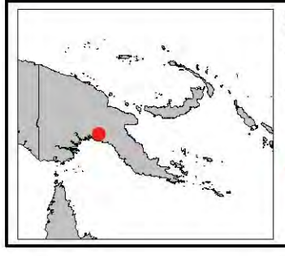
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S13 Flood Depth - 100 year event

Figure: D-129

Rev: A

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N

0 250 500m

Approx. Scale

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Flood Depth (m)

>10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0

22
20
19
17
16
15
14
13
12
11

LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:
Model S14 Flood Depth - 10 year event

Figure: D-130

Rev: A

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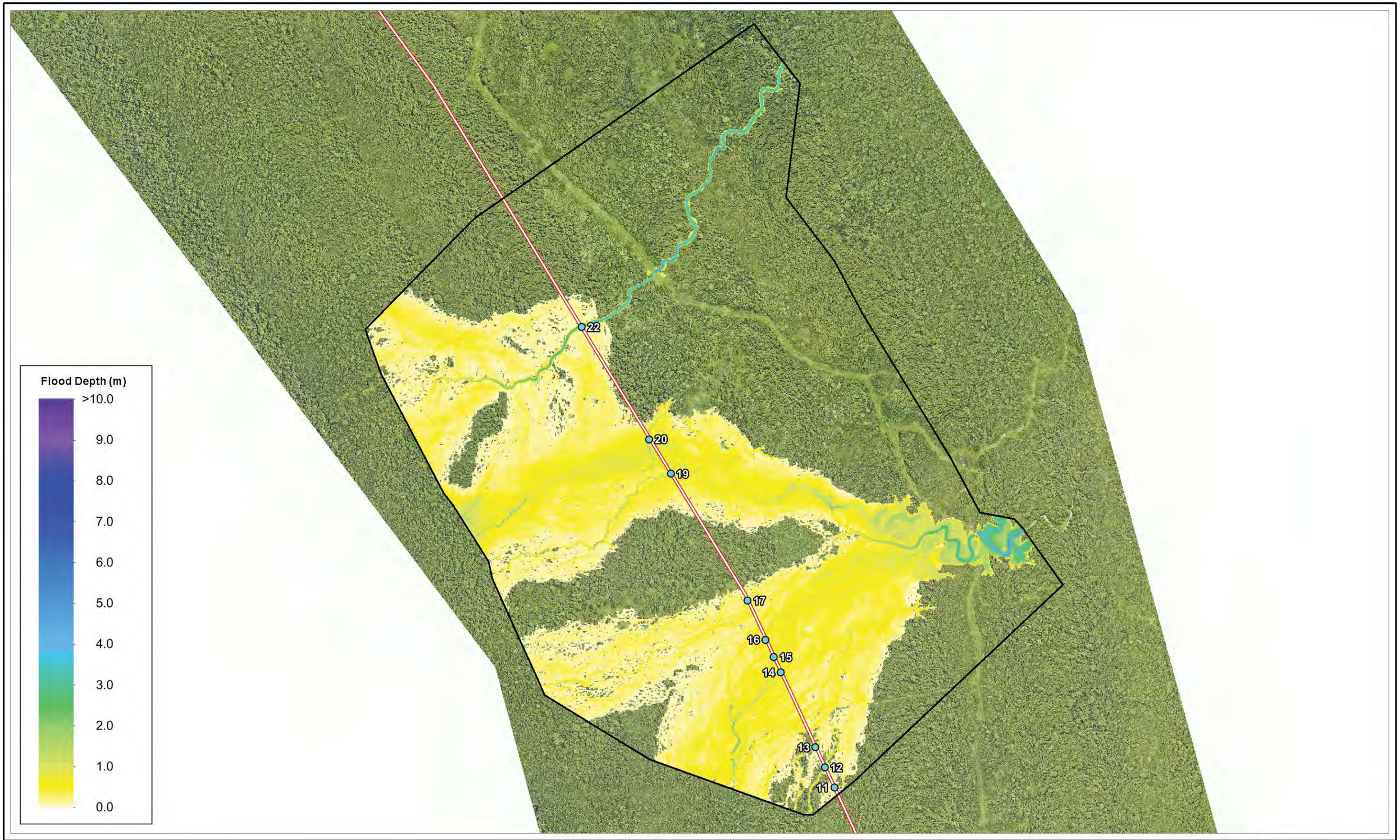
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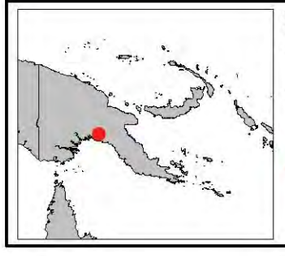
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Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S14 Flood Depth - 50 year event

Figure: D-131

Rev: A

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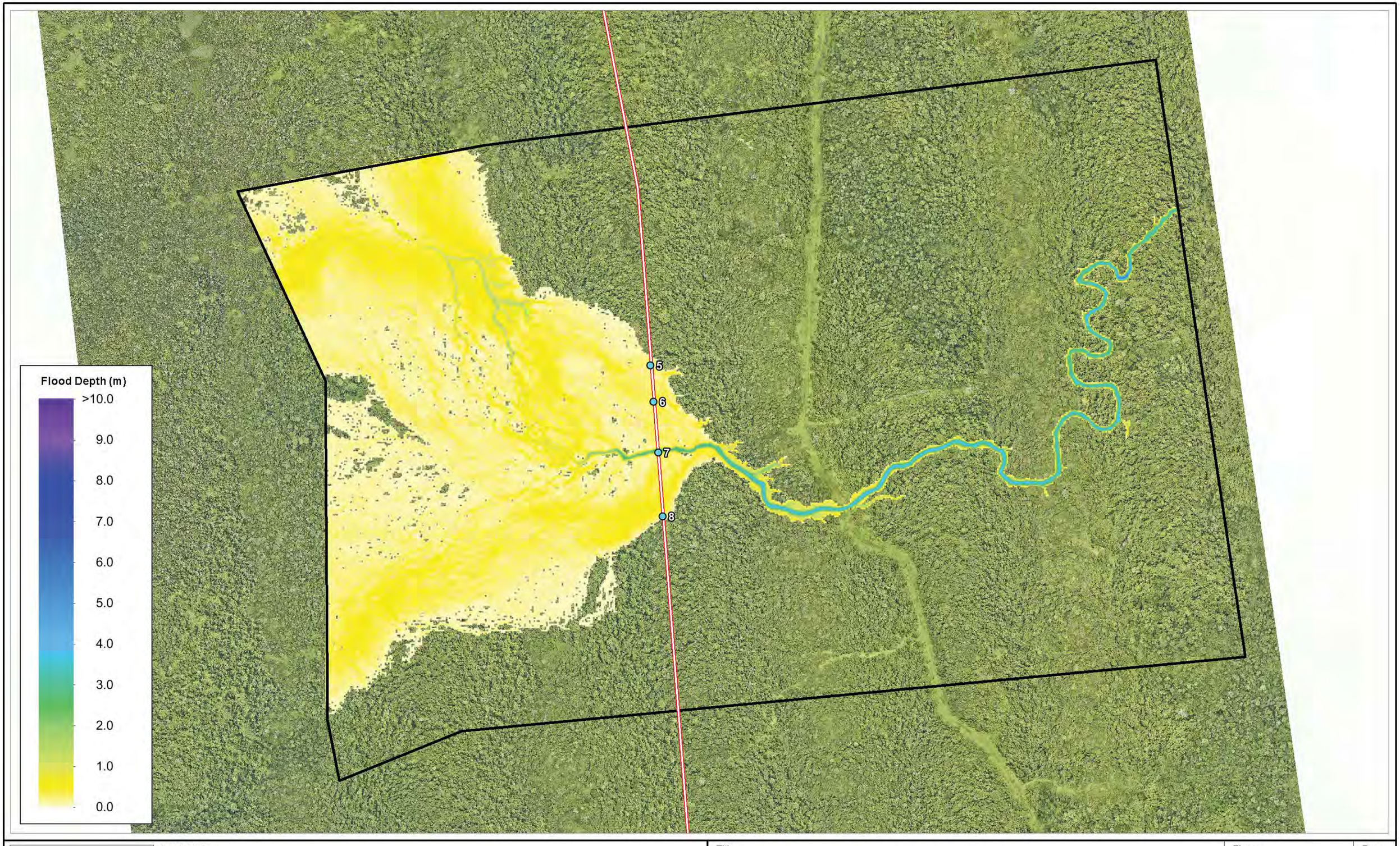
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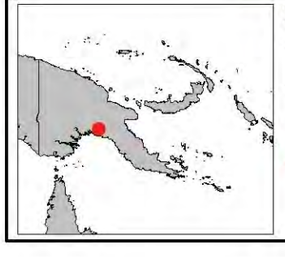
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S16 Depth Levels - 10 year event

Figure: D-133

Rev: A

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0 250 500m

Approx. Scale

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Flood Depth (m)

>10.0

9.0

8.0

7.0

6.0

5.0

4.0

3.0

2.0

1.0

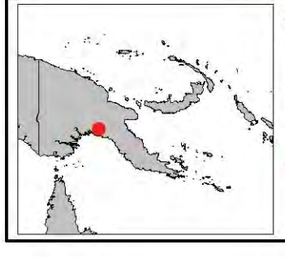
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5

6

7

8



LEGEND

TUFLOW Model Extent

Recording Location

Trunkline Infrastructure Option

Title:

Model S16 Depth Levels - 50 year event

Figure: D-134

Rev: A

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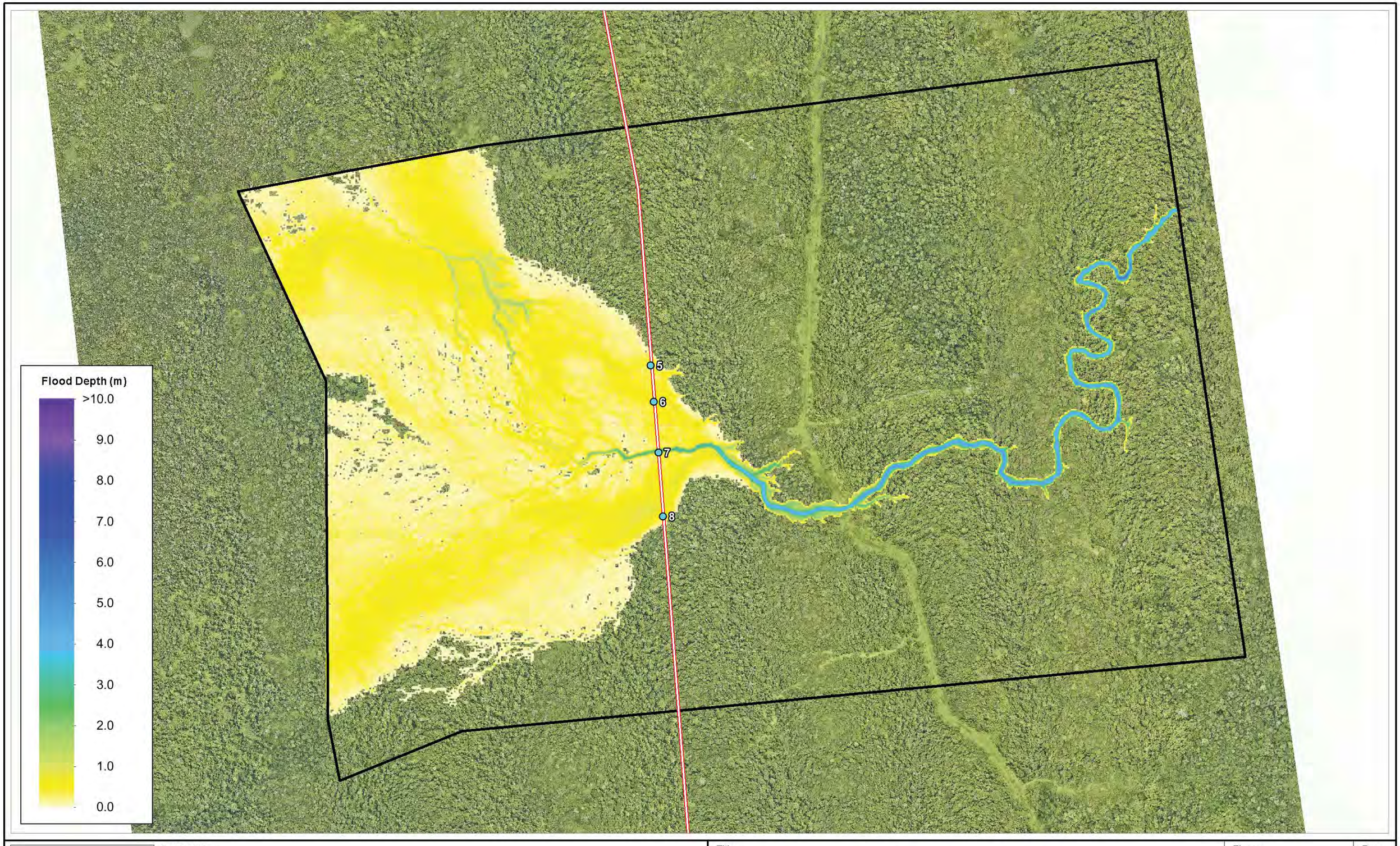
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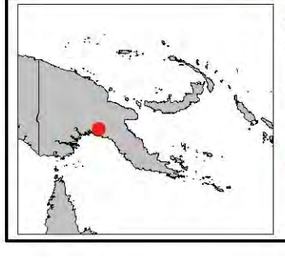
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S16 Depth Levels - 100 year event

Figure: D-135

Rev: A

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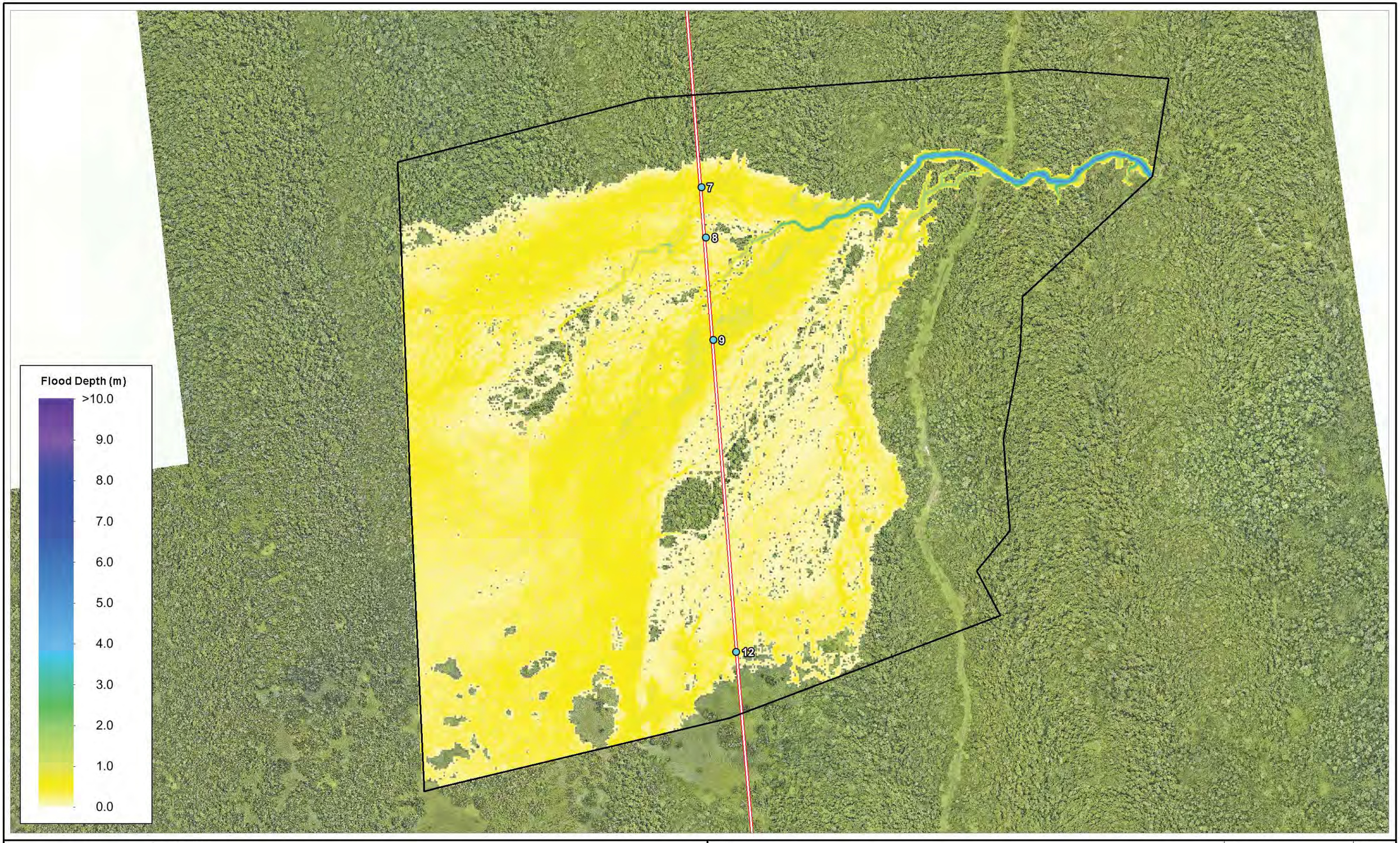
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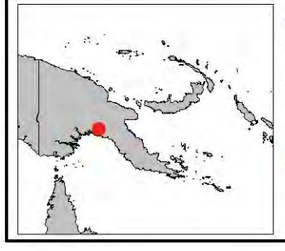
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S17 Flood Depth - 10 year event

Figure: D-136

Rev: A

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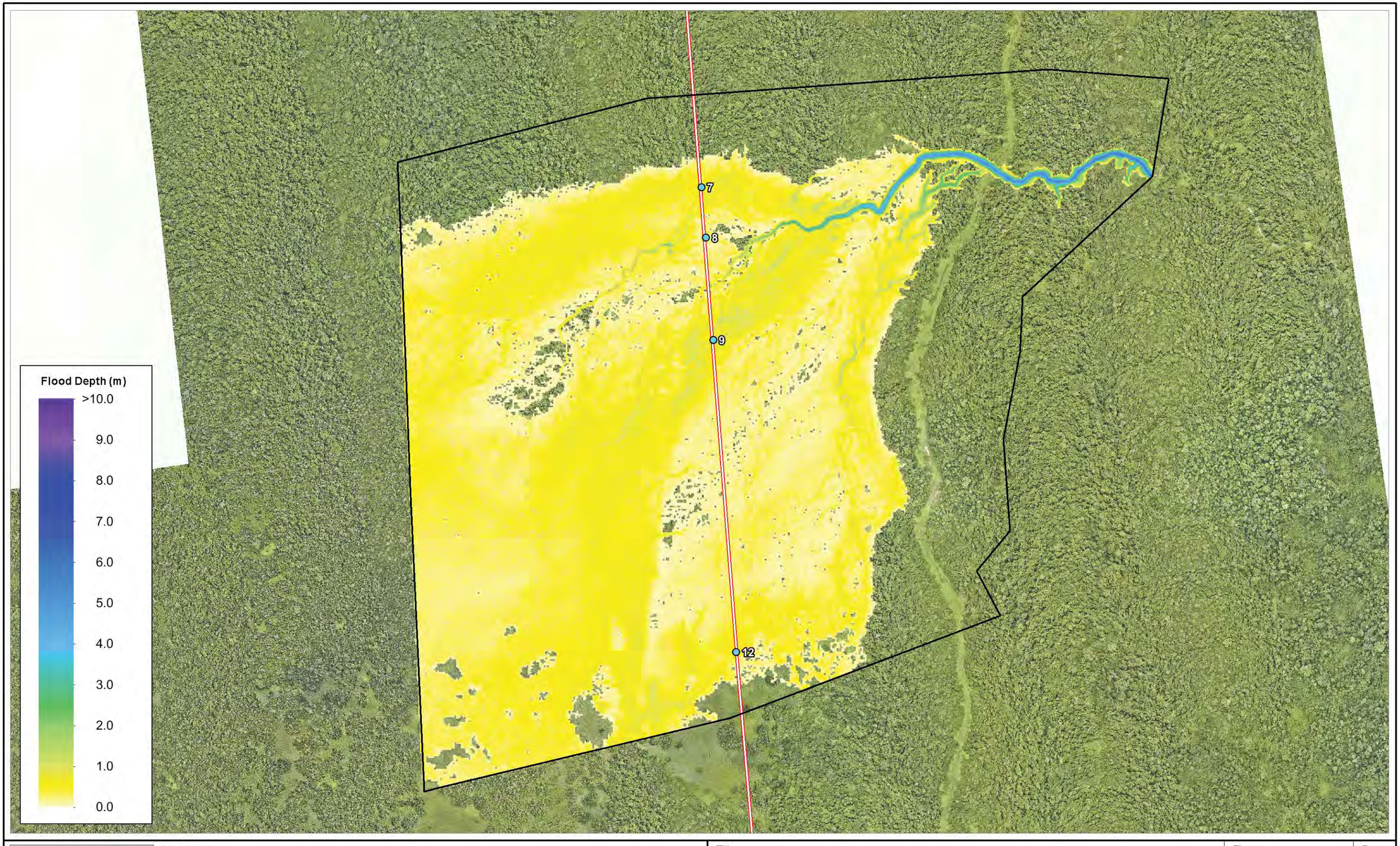
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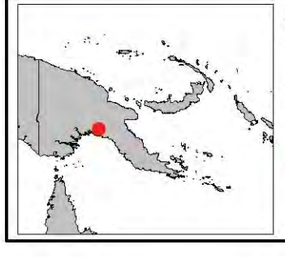
Approx. Scale

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Filepath: I:\B21414_I_GML_Elk_Antelope_EIA_JV\DRG\FloodModelling_170316\FLD_142_170718_S17_d_10y.wor





LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S17 Flood Depth - 50 year event

Figure: D-137

Rev: A

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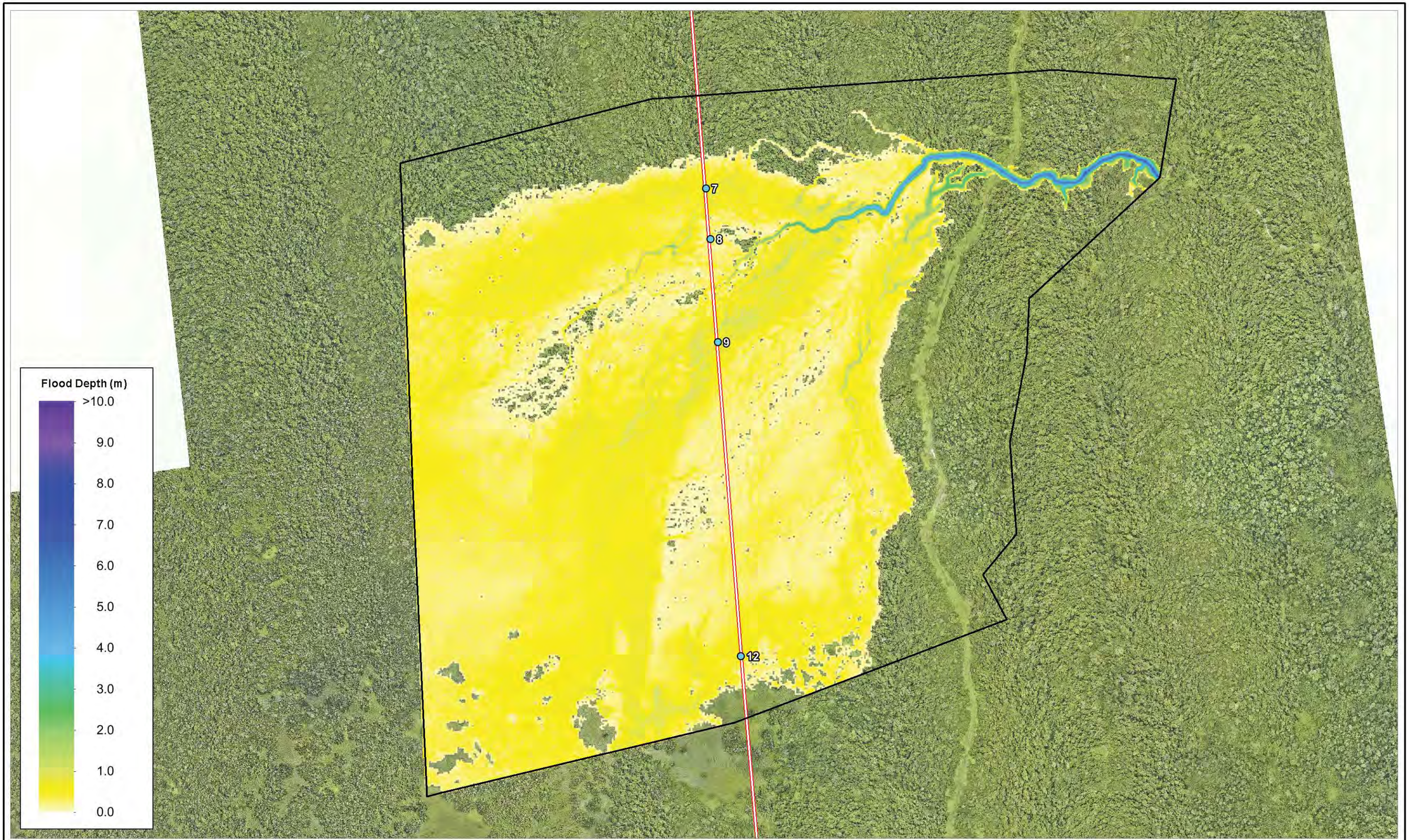
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Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S17 Flood Depth - 100 year event

Figure: D-138

Rev: A

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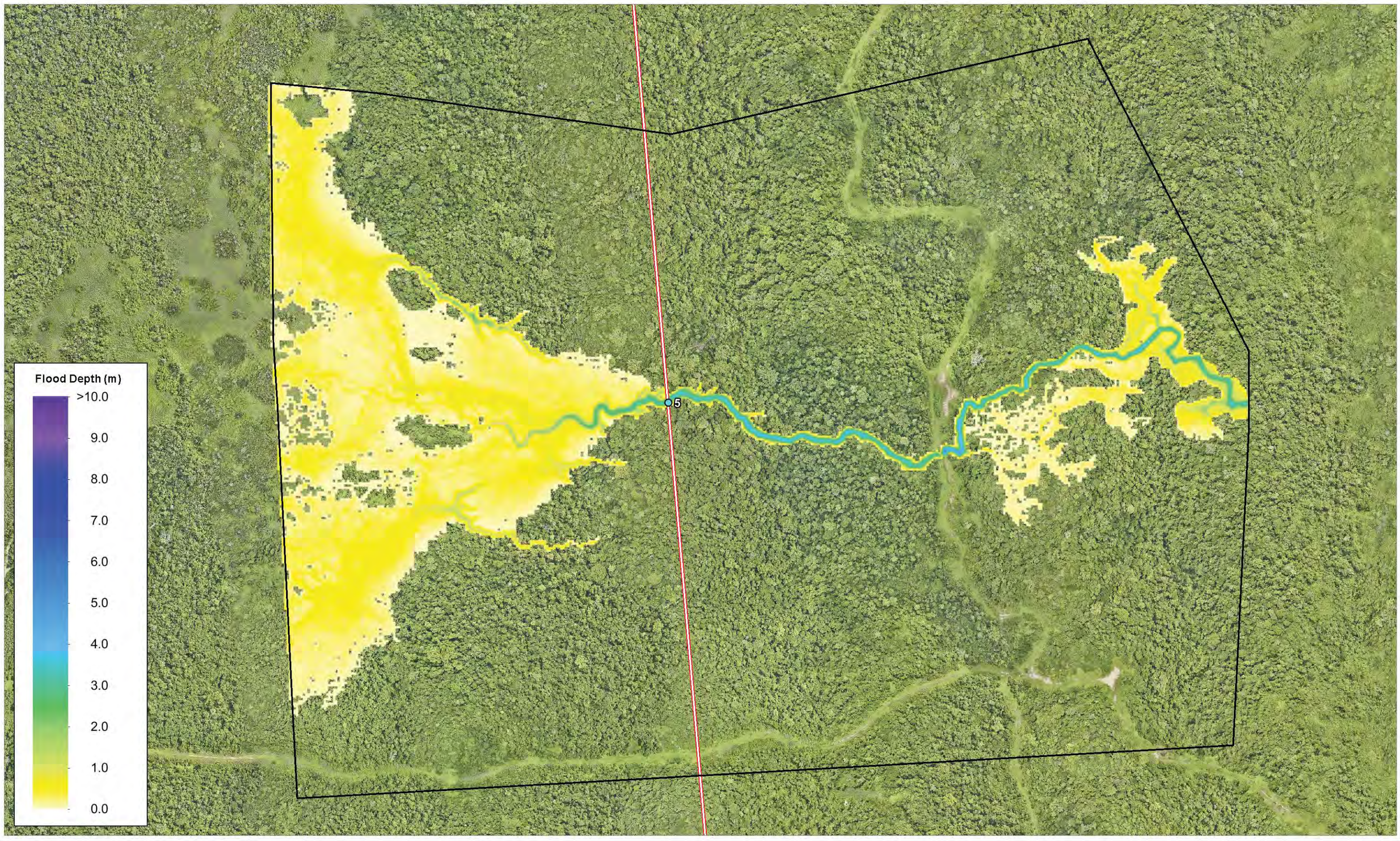
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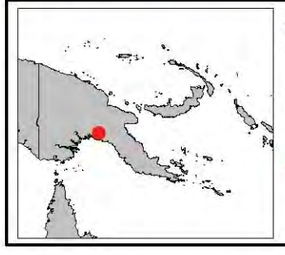
Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S18 Flood Depth - 10 year event

Figure: D-139

Rev: A

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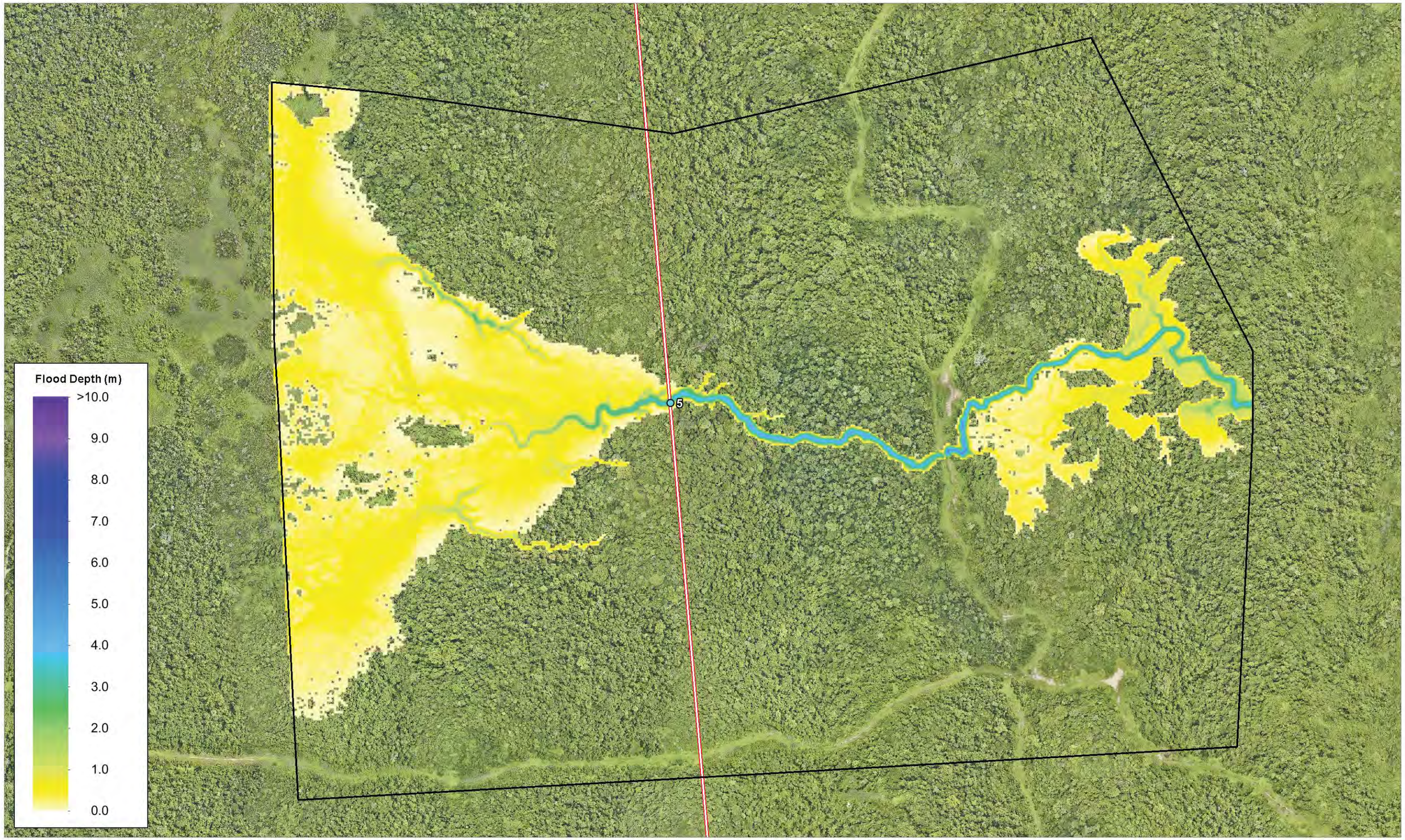
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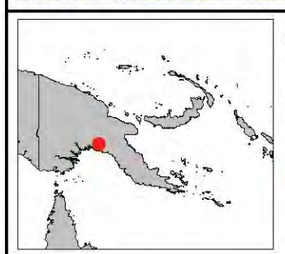
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S18 Flood Depth - 50 year event

Figure: D-140

Rev: A

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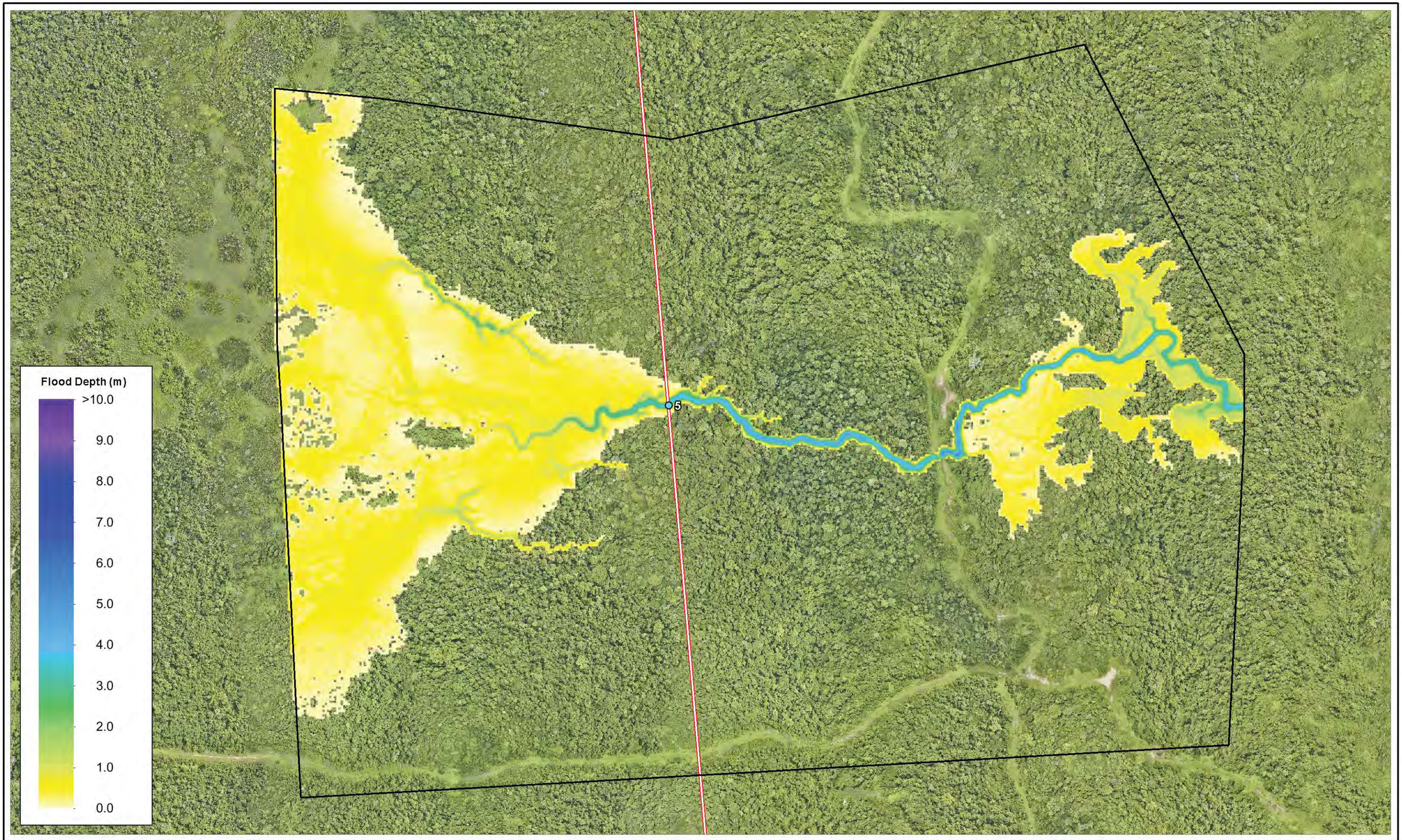
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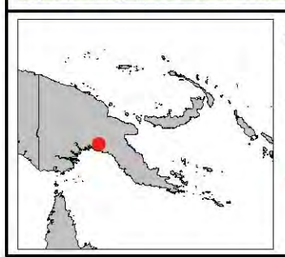
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S18 Flood Depth - 100 year event

Figure: D-141

Rev: A

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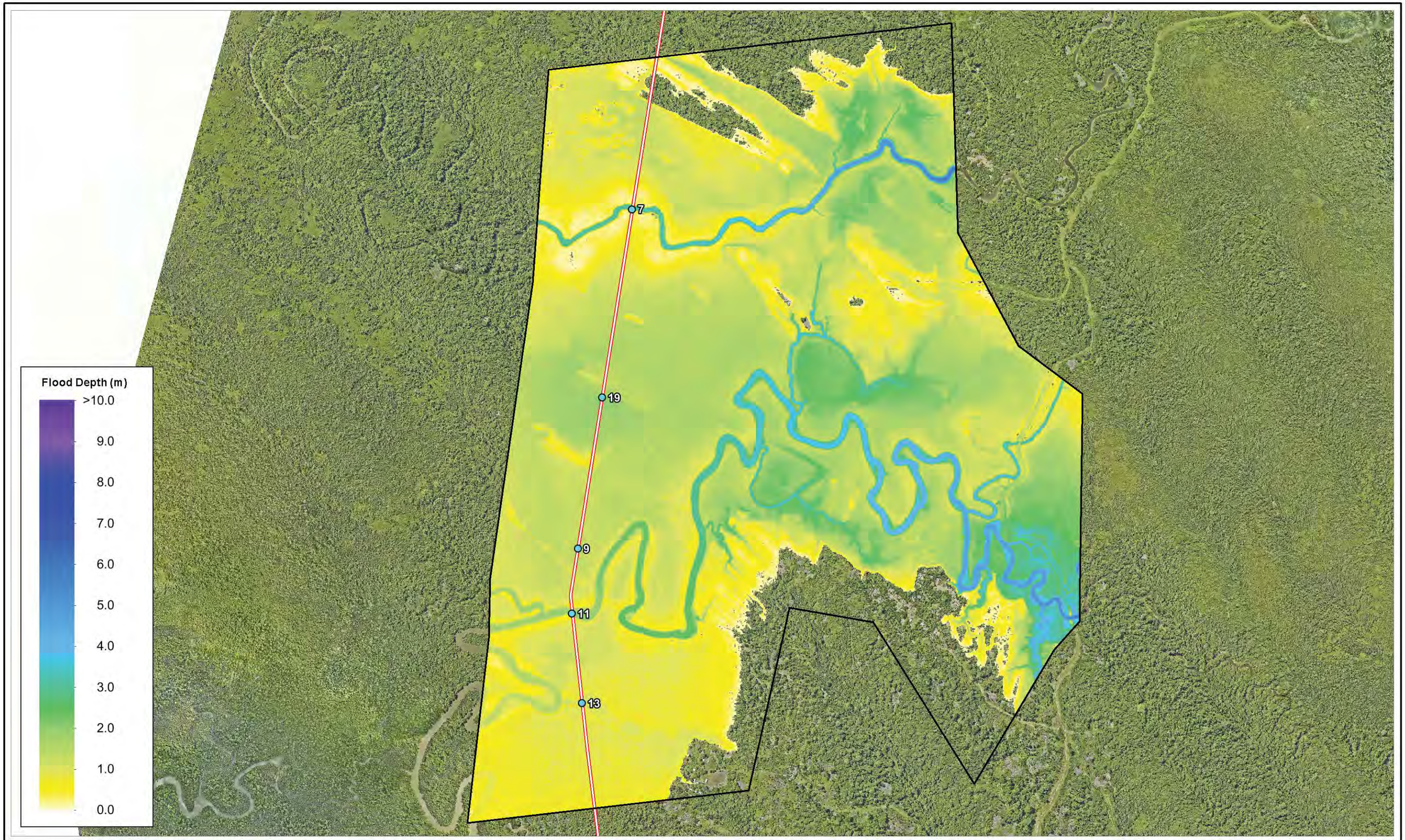
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Approx. Scale

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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S20 Flood Depth - 10 year event

Figure: D-142

Rev: A

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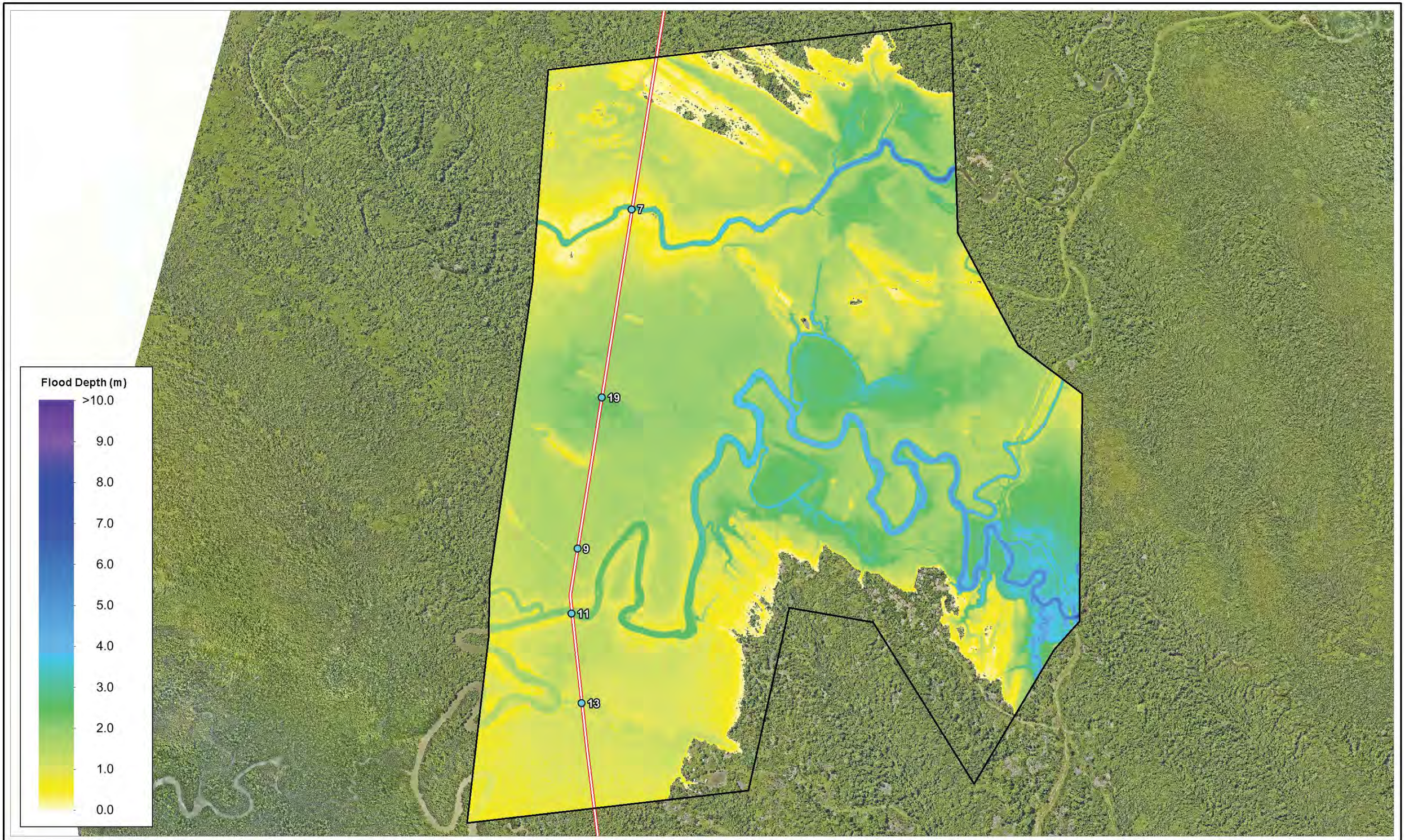
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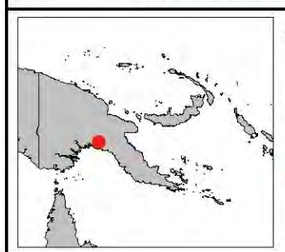
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LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S20 Flood Depth - 50 year event

Figure: D-143

Rev: A

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Approx. Scale

BMT WBM

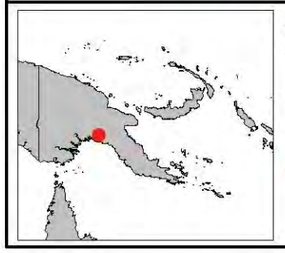
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Flood Depth (m)

>10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0

7
19
9
11
13



LEGEND

- TUFLOW Model Extent
- Recording Location
- Trunkline Infrastructure Option

Title:

Model S20 Flood Depth - 100 year event

Figure: D-144

Rev: A

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N

0 500 1,000m

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BMT WBM Bangalow
6/20 Byron Street, Bangalow 2479
Tel +61 2 6687 0466 Fax +61 2 66870422
Email bmtwbm@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM Brisbane
Level 8, 200 Creek Street, Brisbane 4000
PO Box 203, Spring Hill QLD 4004
Tel +61 7 3831 6744 Fax +61 7 3832 3627
Email bmtwbm@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM Denver
8200 S. Akron Street, #B120
Centennial, Denver Colorado 80112 USA
Tel +1 303 792 9814 Fax +1 303 792 9742
Email denver@bmtwbm.com
Web www.bmtwbm.com

BMT WBM London
International House, 1st Floor
St Katharine's Way, London E1W 1AY
Email london@bmtwbm.co.uk
Web www.bmtwbm.com

BMT WBM Mackay
PO Box 4447, Mackay QLD 4740
Tel +61 7 4953 5144 Fax +61 7 4953 5132
Email mackay@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM Melbourne
Level 5, 99 King Street, Melbourne 3000
PO Box 604, Collins Street West VIC 8007
Tel +61 3 8620 6100 Fax +61 3 8620 6105
Email melbourne@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM Newcastle
126 Belford Street, Broadmeadow 2292
PO Box 266, Broadmeadow NSW 2292
Tel +61 2 4940 8882 Fax +61 2 4940 8887
Email newcastle@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM Perth
Level 4, 20 Parkland Road, Osborne, WA 6017
PO Box 1027, Innaloo WA 6918
Tel +61 8 9328 2029 Fax +61 8 9486 7588
Email perth@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM Sydney
Suite G2, 13-15 Smail Street, Ultimo, Sydney 2007
Tel +61 2 8960 7755 Fax +61 2 8960 7745
Email sydney@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM Vancouver
Suite 401, 611 Alexander Street
Vancouver British Columbia V6A 1E1 Canada
Tel +1 604 683 5777 Fax +1 604 608 3232
Email vancouver@bmtwbm.com
Web www.bmtwbm.com

Appendix B Purari and Aure River Flow Statistics (Pickup and Chewings, 1983)

The following flow statistics are taken from Pickup and Chewings, 1983. They present monthly mean flow (m^3/s) for the Purari and Aure rivers together with statistical analysis.

Table 1. Flow statistics for the Purari River.

Daily discharge statistics (m^3/sec)								
	Raw values				Log_e values			
Month	Mean	Standard deviation	Skewness coefficient	Lag one serial. correl.	Mean	Standard deviation	Skewness coefficient	Lag one serial correl.
Jan.	2603	832	0.732	0.804	7.814	0.319	−0.084	0.828
Feb.	3118	1170	0.706	0.837	7.976	0.376	−0.062	0.857
Mar.	3107	1216	0.585	0.854	7.962	0.408	−0.313	0.884
Apr.	2748	1129	0.868	0.831	7.839	0.400	0.1132	0.863
May	2491	919	1.140	0.796	7.756	0.360	−0.054	0.836
Jun.	2026	1003	1.599	0.825	7.513	0.434	0.506	0.837
Jul.	2024	1198	1.753	0.815	7.464	0.543	−0.002	0.838
Aug.	2156	1202	1.229	0.869	7.524	0.566	−0.190	0.900
Sep.	2112	1239	1.532	0.866	7.490	0.592	−0.233	0.884
Oct.	2594	1177	0.559	0.875	7.741	0.529	−0.915	0.916
Nov.	2119	1084	0.883	0.884	7.530	0.515	−0.036	0.911
Dec.	2529	1111	0.630	0.847	7.736	0.459	−0.224	0.883
Monthly discharge statistics (m^3/sec)								
Jan.	2647	483	0.242	−0.341	7.831	0.184	0.019	−0.330
Feb.	3081	847	0.016	0.045	7.955	0.297	−0.549	0.012
Mar.	3208	815	0.355	0.130	7.993	0.286	−0.371	0.183
Apr.	2755	697	0.329	0.212	7.841	0.255	0.124	0.199
May	2432	611	−0.004	−0.144	7.730	0.265	−0.575	−0.156
Jun.	2026	609	0.999	−0.069	7.513	0.270	0.608	−0.078
Jul.	2038	851	0.525	0.161	7.475	0.422	−0.065	0.242
Aug.	2151	1028	0.676	0.115	7.497	0.514	−0.312	−0.067
Sep.	2204	900	0.525	0.406	7.542	0.461	−0.471	0.154
Oct.	2601	836	−0.305	−0.054	7.744	0.408	−1.051	−0.103
Nov.	2173	856	0.606	−0.419	7.550	0.406	0.126	−0.496
Dec.	2532	762	0.227	0.055	7.739	0.324	−0.114	0.119

Table 2. Flow statistics for the Aure River.

Daily discharge statistics (m^3/sec)								
	Raw values				Log_e values			
Month	Mean	Standard deviation	Skewness coefficient	Lag one serial. correl.	Mean	Standard deviation	Skewness coefficient	Lag one serial correl.
Jan.	336	151	1.284	0.716	5.724	0.435	−0.079	0.782
Feb.	449	272	1.662	0.771	5.958	0.532	0.449	0.818
Mar.	388	196	1.253	0.747	5.848	0.471	0.218	0.816
Apr.	383	188	1.331	0.619	5.840	0.459	0.219	0.731
May	335	173	2.079	0.687	5.709	0.452	0.263	0.753
Jun.	199	101	2.152	0.704	5.192	0.433	0.482	0.784
Jul.	201	139	1.955	0.663	5.103	0.639	0.043	0.814
Aug.	150	92	1.700	0.757	4.853	0.548	0.352	0.867
Sep.	155	113	2.044	0.791	4.834	0.628	0.394	0.851
Oct.	298	199	1.583	0.839	5.488	0.671	−0.316	0.882
Nov.	241	162	2.083	0.777	5.312	0.574	0.397	0.860
Dec.	318	190	1.802	0.653	5.600	0.580	−0.088	0.818
Monthly discharge statistics (m^3/sec)								
Jan.	329	107	−0.039	−0.619	5.962	0.354	−0.582	−0.598
Feb.	460	195	0.661	−0.160	5.976	0.391	0.334	−0.132
Mar.	404	98	−0.093	0.063	5.905	0.261	0.565	0.039
Apr.	394	106	0.706	−0.061	5.876	0.266	0.271	−0.050
May	312	107	−0.637	0.172	5.606	0.404	−1.169	0.061
Jun.	188	59	0.808	−0.137	5.137	0.300	−0.294	−0.138
Jul.	189	72	−0.225	0.025	5.055	0.455	−0.516	−0.049
Aug.	142	44	−0.368	0.166	4.822	0.336	−0.614	0.025
Sep.	142	57	0.712	0.834	4.758	0.362	−0.212	0.623
Oct.	238	111	0.398	0.499	5.271	0.525	−0.147	0.400
Nov.	288	215	1.881	−0.125	5.405	0.586	1.207	−0.096
Dec.	319	132	0.488	−0.187	5.604	0.438	0.039	−0.198



BMT WBM Bangalow
6/20 Byron Street, Bangalow 2479
Tel +61 2 6687 0466 Fax +61 2 66870422
Email bmtwbm@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM Brisbane
Level 8, 200 Creek Street, Brisbane 4000
PO Box 203, Spring Hill QLD 4004
Tel +61 7 3831 6744 Fax +61 7 3832 3627
Email bmtwbm@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM Denver
8200 S. Akron Street, #B120
Centennial, Denver Colorado 80112 USA
Tel +1 303 792 9814 Fax +1 303 792 9742
Email denver@bmtwbm.com
Web www.bmtwbm.com

BMT WBM London
International House, 1st Floor
St Katharine's Way, London E1W 1AY
Email london@bmtwbm.co.uk
Web www.bmtwbm.com

BMT WBM Mackay
PO Box 4447, Mackay QLD 4740
Tel +61 7 4953 5144 Fax +61 7 4953 5132
Email mackay@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM Melbourne
Level 5, 99 King Street, Melbourne 3000
PO Box 604, Collins Street West VIC 8007
Tel +61 3 8620 6100 Fax +61 3 8620 6105
Email melbourne@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM Newcastle
126 Belford Street, Broadmeadow 2292
PO Box 266, Broadmeadow NSW 2292
Tel +61 2 4940 8882 Fax +61 2 4940 8887
Email newcastle@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM Perth
Level 4, 20 Parkland Road, Osborne, WA 6017
PO Box 1027, Innaloo WA 6918
Tel +61 8 9328 2029 Fax +61 8 9486 7588
Email perth@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM Sydney
Suite G2, 13-15 Smail Street, Ultimo, Sydney 2007
Tel +61 2 8960 7755 Fax +61 2 8960 7745
Email sydney@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM Vancouver
Suite 401, 611 Alexander Street
Vancouver British Columbia V6A 1E1 Canada
Tel +1 604 683 5777 Fax +1 604 608 3232
Email vancouver@bmtwbm.com
Web www.bmtwbm.com