

ONRUS C2C

Hydrology Assessment

Report Prepared for

Anchor Environmental



Report Prepared by



December 2024

ONRUS C2C: Hydrology Assessment

Anchor Environmental

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SRK Project Number 610391

December 2024

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Executive Summary

A Situation Assessment report on the state of the Onrus River Catchment is required as part of the Onrus Catchment-to-Coast Rehabilitation and Restoration Project. As part of this assessment a hydrological study is required to provide:

- An assessment of the extent and intensity of invasion by alien plants and of levels of transformation and land degradation in the Onrus catchment and
- Quantification of historical changes in streamflow across the Onrus catchment and identify key drivers of change.

Summary of principal objectives

The objectives of the project and assessment of success achieved in each of these are listed below:

- Assemble long-term records of observed discharge in the Onrus river and meteorological data for use in runoff simulations. This was successfully achieved by assessing the 48 years of daily flow records of the G4H033 station in the upper part of the catchment. Rainfall and evaporation records were assembled by successfully matching and extending observed daily records with global datasets.
- The catchment watershed was defined using a Digital Elevation Model and was found to lie mostly on the G40H Quaternary boundary, but within the Quaternary catchment boundary in places.
- Alien species mapping was achieved by combining satellite imagery and bandwidth algorithms with on-site observations and local knowledge. Three distinct stages of alien infestation were delineated, including status in 2018, 2021 and 2024.
- Land uses for natural and current conditions were derived from national sources and combined with topographic and soils information to prepare input parameters for a deterministic hydrological model.
- The model was successfully applied to simulate six different land use scenarios, including fictitious increases and decreases in alien species infestation and irrigation abstractions.

Results

The following results emanated from the hydrological assessment of the Onrus catchment:

- The full record of 47 years (1977 – 2023) of observed flows at the G4H033 weir has been assessed and nuances highlighted.
 - A very abrupt change in cumulative discharge is evident from April 1993 onward with the Mean Annual Runoff pre-April 1993 being some 20 Mm³/annum, and that post-April 1993 being 7.0 Mm³/annum.
 - The flow record post-April 1993 contains a period (more than four continuous years) of low flows averaging 2.7 Mm³/annum and a similar period of high flows averaging 13.3 Mm³/annum.
- Alien vegetation infestation into the catchment, mainly along water courses, has been determined using satellite imagery, colour band algorithms and *in-situ* observations.
 - The alien infestation has increased some ten-fold between 2018 and 2024. Aliens were estimated to cover 0.82 km² of the catchment in 2018 and 8.6 km² in 2024, being almost 16% of the total catchment area.
 - Increased alien infestation into 50% of the remaining current Fynbos in the catchment is simulated to likely reduce the catchment runoff by a further 15%.
- Simulated runoff of six land use scenarios revealed that:
 - The current land use, including current alien vegetation distribution and estimated irrigation abstractions results in a drop in runoff of 20% of natural vegetation land use.

- Increases in alien infestation could easily cause a further 15% reduction in catchment runoff.
- Removal of aliens and curtailing all irrigation abstractions could improve the average runoff yield by 35%.
- Extreme runoff estimates predict a 1:100-year Return Interval event in the upper catchment, upstream of the de Bos dam of 120 m³/s. due to the steep mountain slopes bordering the valley. Similar events contribute a peak flow from the catchment between the de Bos dam and the Wetland, of 41 m³/s, while the catchment between the Wetland and the Estuary produces 42 m³/s.
- Future Climate Change impacts on average annual and extreme events include:
 - A 10 to 20% decrease in average annual runoff in the near future (2015 to 2044) and a 40 to 50% decrease in the distant future (2070 to 2099).
 - A possible increase in extreme event discharge of 10 to 15%.

Recommendations

Based on the hydrological assessment, the following recommendations are offered:

The abrupt change in observed discharge in April 1993 needs to be investigated in terms of:

- Rating curve error
- Damage to the structure
- Excessive upstream land use change and/or abstractions

The management of the de Bos dam and flow release requirements need to be confirmed to:

- Improve the prediction of flow regimes in the lower catchments
- Allow for the simulation of alternate dam operation and release scenarios to be evaluated, including environmental flow release requirements

Catchment runoff simulations need to be improved by:

- Better delineation and species identification of alien vegetation
- In-situ soils (hydropedological) and vegetation surveys
- Including observed alien species uptake and wetland mechanisms into the simulation model

The following monitoring needs to be installed:

- De Bos Dam outlet releases
- Any run-of-river abstractions
- A network of meteorological stations covering hillslopes and valleys

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Disclaimer

The opinions expressed in this Report have been based on the information accessed by SRK Consulting (South Africa) (Pty) Ltd (SRK) from the Department of Water and Sanitation (DWS). The opinions in this Report are provided in response to a specific request from Anchor Environmental to do so. SRK has exercised all due care in reviewing the available information. Whilst SRK has compared key data with expected values, the accuracy of the results and conclusions from the assessment are entirely reliant on the accuracy and completeness of the accessed data. SRK does not accept responsibility for any errors or omissions in the accessed information and does not accept any consequential liability arising from commercial decisions or actions resulting from them. Opinions presented in this report apply to the site conditions and features as they existed at the time of SRK's investigations, and those reasonably foreseeable. These opinions do not necessarily apply to conditions and features that may arise after the date of this Report, about which SRK had no prior knowledge nor had the opportunity to evaluate.

List of Abbreviations

AMS	Annual Maximum Series
ACRU	Agricultural Catchments Research Unit model
ARC-ISCW	Agricultural Research Council 's Institute for Soil, Climate and Water
AUC-ROC	Area Under the Curve of the Receiver Operating Characteristic
CWRR	Centre for Water Resources Research
DEM	Digital Elevation Model
DUL	Drained Upper Limit
ERA5	Fifth generation ECMWF atmospheric reanalysis of the global climate
GCM	General Circulation Model
GEE	Google Earth Engine
GEV	General Extreme Value
GIS	Geographic Information System
HRUs	Hydrological Response Units
LN	log Normal
LP3	log-Pearson-III
LCUClass	Land Use Land Cover Class
LULC	Land Use Land Cover
MAE	Mean Annual Evaporation
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
NLC	National Land Cover
OA	Overall Accuracy
PA	Producer Accuracy
RF	Random Forest
RI	Return Interval
RGB	Red-Green-Blue
SAR	Synthetic Aperture Radar
SRTM	Shuttle Radar Topography Mission
TSA	Time Series Analysis
WaPOR	Water Productivity through Open access of Remotely sensed derived data
WMA	Water Management Area
UA	User Accuracy

1 Introduction and Scope of Report

Anchor Environmental Consultants (Pty) Ltd (Anchor) were approached by the Overstand Municipality to prepare a Situation Assessment report on the state of the Onrus River Catchment as part of the Onrus Catchment-to-Coast Rehabilitation and Restoration Project. The situation assessment is required to inform the development of a Catchment-to-Coast Rehabilitation and Restoration Plan. As part of this assessment Anchor commissioned SRK Consulting SA (SRK), to provide:

- An assessment of the extent and intensity of invasion by alien plants and of levels of transformation and land degradation in the Onrus catchment and
- Quantification of historical changes in streamflow across the Onrus catchment and identify key drivers of change.

This document presents the results of alien invasion assessment over the past six years and the current levels of land degradation in the Onrus catchment. The results of a detailed assessment of the observed discharge and simulated runoff from selected land-use scenarios are also included to illustrate the degree of perturbation to resultant flow regimes.

2 Program Objectives

2.1 Program Objectives

The objectives of the project and assessment of success achieved in each of these are listed below:

- Assemble long-term records of observed discharge in the Onrus river and meteorological data for use in runoff simulations. This was successfully achieved by assessing the 48 years of daily flow records of the G4H033 station in the upper part of the catchment. Rainfall and evaporation records were assembled by successfully matching and extending observed daily records with global datasets.
- The catchment watershed was defined using a Digital Elevation Model and was found to lie mostly on the G40H Quaternary boundary, but within the Quaternary catchment boundary in places.
- Alien species mapping was achieved by combining satellite imagery and bandwidth algorithms with on-site observations and local knowledge. Three distinct stages of alien infestation were delineated, including status in 2018, 2021 and 2024.
- Land uses for natural and current conditions were derived from national sources and combined with topographic and soils information to prepare input parameters for a deterministic hydrological model.
- The model was successfully applied to simulate six different land use scenarios, including fictitious increases and decreases in alien species infestation and irrigation abstractions.

2.2 Project team

The following team members contributed to the outcome of this assessment:

Dr Simon Lorentz	SRK	Project Manager, Hydrology Review and Reporting.
Ms Kershani Chetty	UKZN	Managed Remote Sensing and Hydrological simulation tasks.
Dr Shaeden Gokool	UKZN	Hydrological Modelling, GIS and Remote Sensing.
Dr Maqsooda Mahomed	UKZN	Hydrological Modelling, Data analysis, Reporting.

3 Onrus Catchment Characteristics

3.1 Catchment Description

The Onrus catchment lies within the Overstrand Local Municipality (OLM, part of the Overberg District Municipality) in the Western Cape Province (Figure 3-1) and is included in the Breede-Gouritz Catchment Management Area of South Africa (Breede-Gouritz Catchment Management Strategy, 2017; SAS, 2019). The sub-catchments of the Breede WMA are characterized by the rolling hills of the Overberg (Breede-Gouritz Catchment Management Strategy, 2017). The Overberg region is divided into two sub-areas, namely the Overberg East and the Overberg West (Department of Water Affairs and Forestry, 2004). The Overberg East sub-area includes the catchments of the Sout, Kars and Nuwejaars Rivers in one secondary catchment, namely G50 (Department of Water Affairs and Forestry, 2004). The Overberg West sub-area includes the coastal catchments extending from the Palmiet River in the west to the Uilkraals River in the east (Department of Water Affairs and Forestry, 2004), this area is the secondary catchment G40 (Department of Water Affairs and Forestry, 2004).

Amongst the rivers present in the Overberg West region, in the west is the Onrus River (within quaternary catchment G40H, Figure 3-1), with current water uses being mainly for domestic and irrigation purposes (Department of Water Affairs and Forestry, 2004). The river lies within the quaternary catchment and discharges to the ocean via the Onrus estuary (Department of Water Affairs and Forestry, 2004). The river has a small catchment area of 55 km² and the main-stem river is approximately 16.5 km long from source to mouth (Heinecken & Damstra 1983). In the Onrus River's mid to lower reaches, the river supports extensive and ecologically important wetlands, including peatlands. The river flows through cultivated lands for much of its middle reaches where the river consists of a single channel and the riparian zone is heavily invaded with alien woodland.

It is in this reach that the river is impounded by the de Bos Dam. The dam was constructed in 1976 approximately 9 km upstream of the estuary mouth in the narrow Attacques Kloof (Massie and Clark, 2016). It is the only dam in the Overberg region; however, several small farm dams are also present within the Onrus River catchment (Department of Water Affairs and Forestry, 2004; Massie and Clark, 2016). The de Bos Dam has a storage capacity of 6,3 million m³, an annual supply capacity of approximately 3.3 Mm³ (Du Plessis 1995), supporting irrigation to various farms in the valley and supplying domestic water to the Greater Hermanus area (Department of Water Affairs and Forestry, 2004; Breede-Gouritz Catchment Management Strategy, 2017; Massie and Clark, 2016). The compensation releases are approximately 0,5 million m³/a to supply irrigators downstream of the dam, together with a supplementary environmental release of 1.6 Mm³ per annum, (0.066 m³/s), (Massie and Clark, 2016). According to the DWAF (1996) estimates, the portion of the Onrus River catchment below the de Bos Dam contributes some 42% of the natural Mean Annual Runoff (MAR) of the whole catchment.

3.2 Catchment Topography

In the upper Onrus catchment, steep mountain slopes run parallel to the valley (Figure 3-2), leading to rapid and large runoff responses. The slopes of these contributing mountains reach 8.2, while the valley section slopes are some 0.1. The longitudinal slope in the Onrus river above the de Bos dam is approximately 0.029, while below the dam the river gradient reduces to 0.015.

3.3 Land Use

The Onrus catchment falls within the Fynbos Biome, however, through various catchment developments, most of the area has been transformed (Massie and Clark, 2016; Western Cape Government, 2021). Current Land Use has been extracted from the 2022 South African National Land Cover (NLC) data (1990-2022) (Figure 3-3).

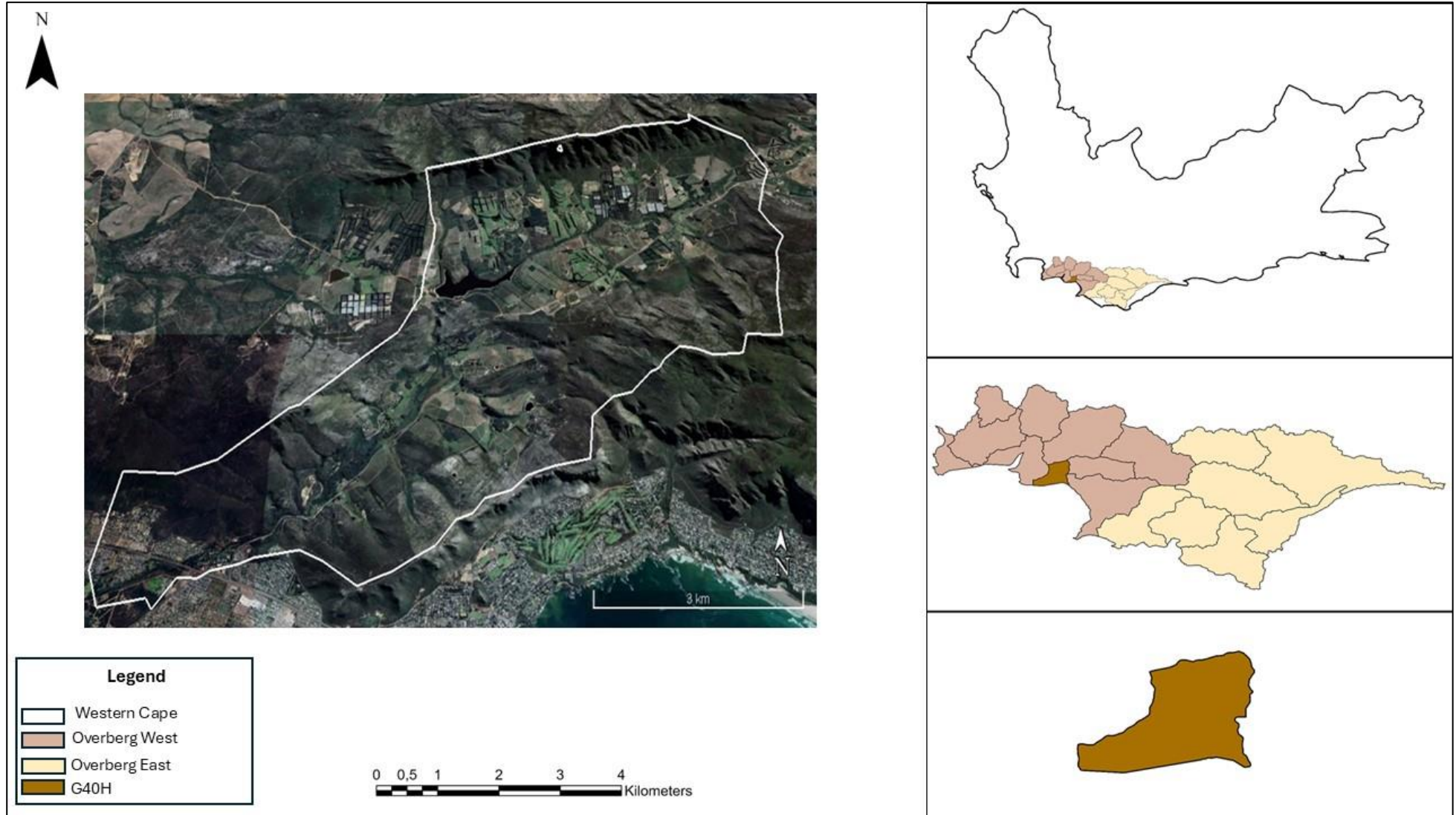


Figure 3-1: Onrus catchment location and boundary.

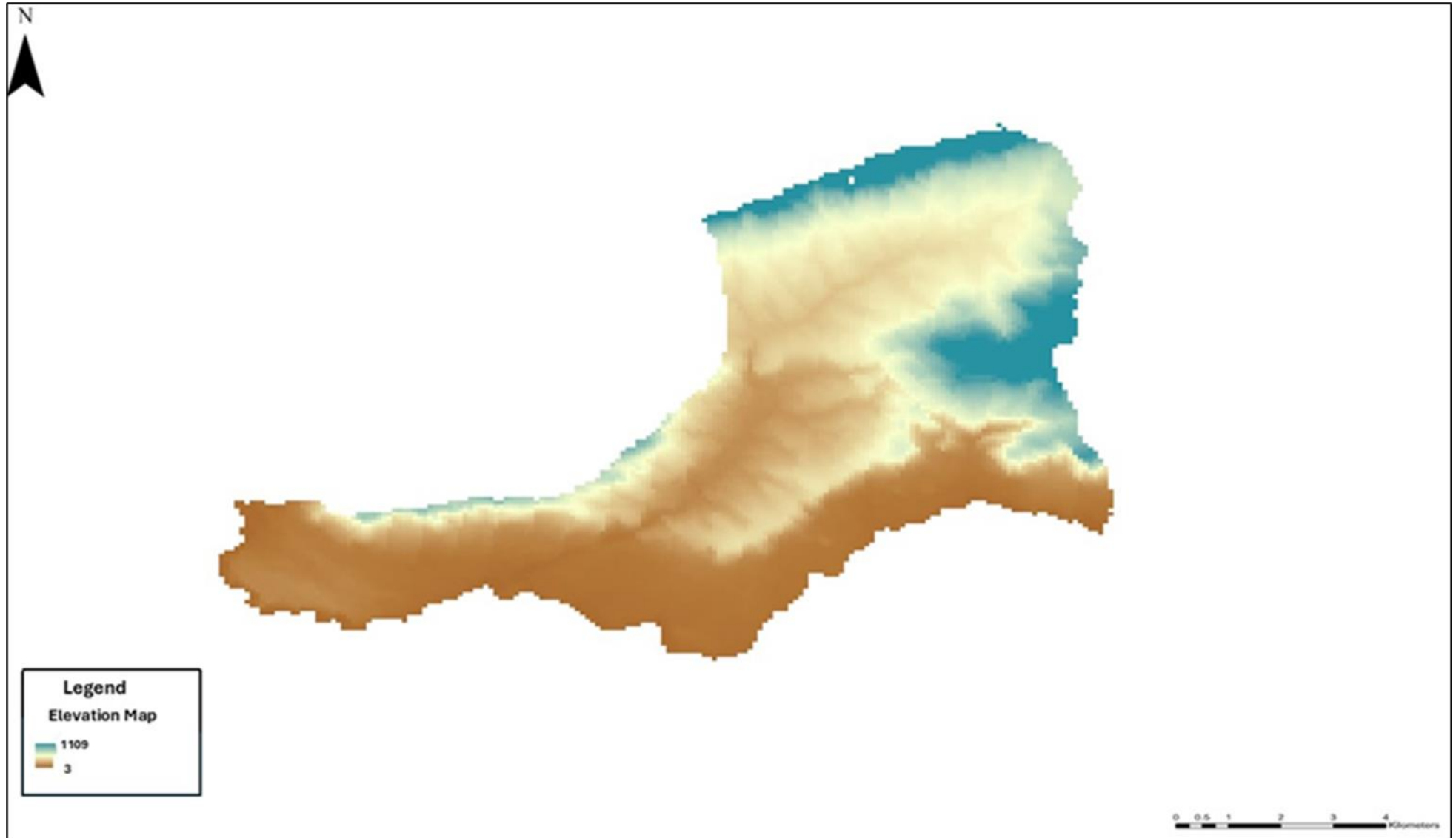


Figure 3-2: Onrus catchment elevation DEM for South Africa 30m – Shuttle Radar Topography Mission (Weepener et al., 2011).

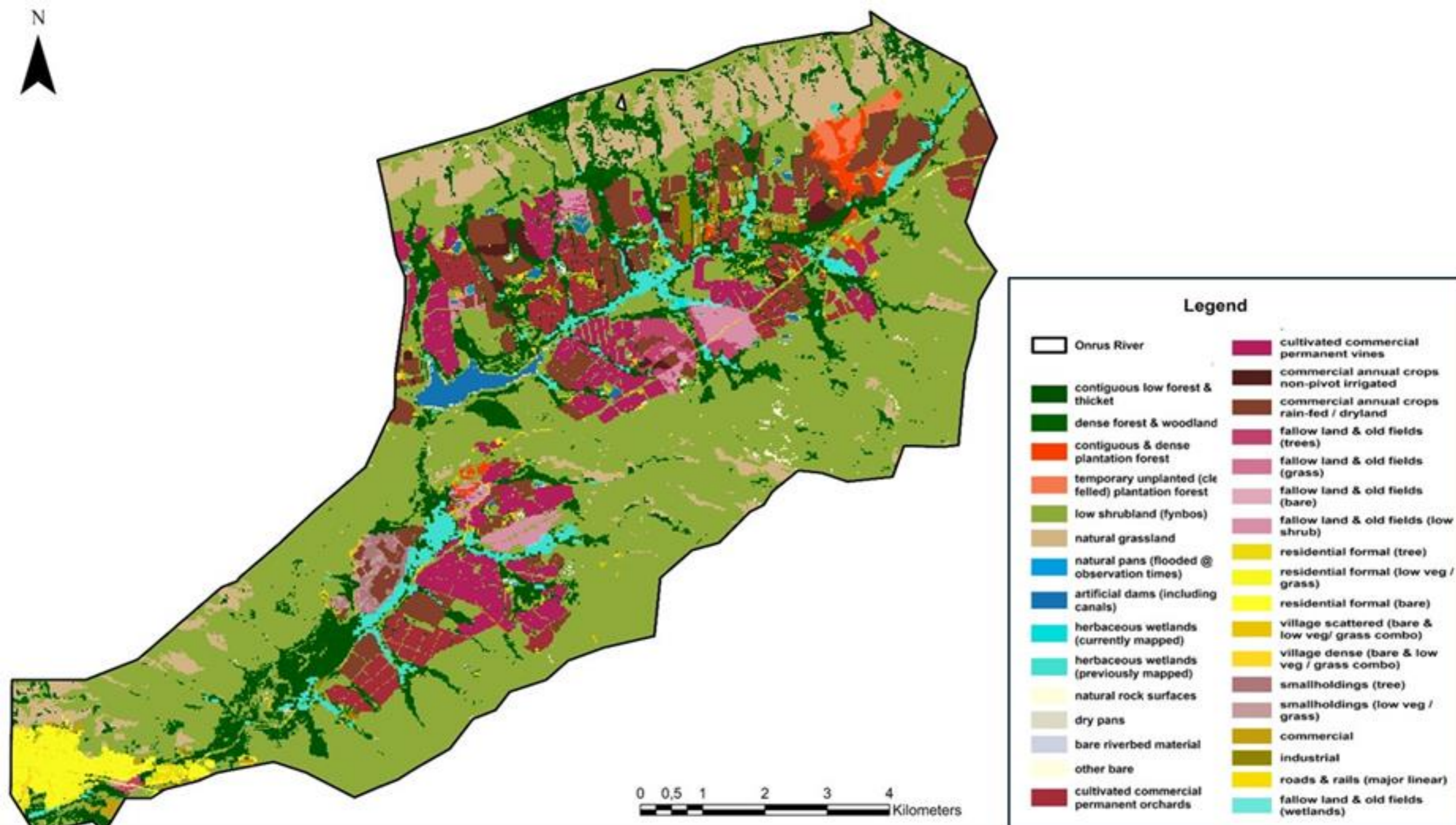


Figure 3-3: Onrus catchment current Land Cover (South African NLC dataset 2022).

The river course is heavily overgrown with invasive alien vegetation, including eucalyptus species (Massie and Clark, 2016; Western Cape Government, 2021). Coinciding with the above-described features are two dominant vegetation types in the catchment: Overberg Sandstone Fynbos and Elim Ferricrete Fynbos.

Downstream of the de Bos dam, the Onrus river is joined by two of its major tributaries - an unnamed stream and the Antjies River (Belcher and Grobler, 2020). At the confluence of these three watercourses, the Onrus River widens to form a wetland that was previously recognized with high ecological importance and sensitivity due to its deep peat profile. However, the wetland has been degraded due to prolonged drying, burning and subsequent flooding (September 2023). The Onrus wetland vegetation mainly comprises endemic palmiet (*Prionium serratum*) (Grundling et al., 2019, Water Research Commission, 2023). Palmiet wetlands are endemic to the coastal provinces of South Africa; are estimated to comprise less than 10% of South Africa's wetlands and are considered globally unique in their distribution (Grundling et al., 2019).

3.4 Geology

The dominant geology in the Onrus catchment is the Table Mountain Group, with Bokkeveld Group dominant in a strip entering the catchment from the north-eastern side and providing the distinctive elbow in the Onrus river, where the de Bos dam is located. Rolling hills characterize and dominate the topography of the Onrus catchment (Figure 3-2). The Onrus River rises in the Babilonstoring Mountains. It flows approximately 16 km through the Hemel en Aarde Valley (located between two mountain ridges) before crossing the narrow coastal plain to discharge into the sea via Onrus estuary (Western Cape Government, 2021). The wide upper Hemel en Aarde Valley lies at an altitude of 600-1000 m and is separated from the lower Hemel en Aarde valley, a much narrower valley at an altitude of 200-400 m (Massie, V and Clark, BM. 2016). Considering the Onrus River is situated in a valley bottom with steep slopes on either side, this makes it susceptible to rapid responses and extreme events.

3.5 Soils

Quartzitic, sandy soils are derived from Table Mountain Sandstone, and clay-rich, gravelly soils derived from the Bokkeveld Shale, ironstone and granite. Also, present are isolated strips of Western Coastal Shale Band derived soils, while Hangklip Sands and Overberg Dunes occur on the coastal plain (Massie and Clark, 2016)

3.6 Climate

Climate data (to represent daily temperature, rainfall, and reference Evapotranspiration (ET)) was extracted from the national Quinary catchment database (Maherry et al., 2013) for the period 1950-1999, whereas, for the period 1999-2023, temperature and rainfall were obtained from ERA5 (Copernicus Climate Change Service, Climate Data Store, 2021) and checked against observed rainfall records. Reference ET was derived from WaPOR (FAO 2018; 2020) global datasets, estimated using Hargreaves and Samani (1985).

Although the data were derived on a daily basis, the average monthly rainfall and A-Pan equivalent evaporation are shown in Figure 3-4. Rainfall peaks in the winter months, with low rainfall in the summer. Alternatively, the evaporation potential peaks in the summer months and reduces in winter.

The Mean Annual Precipitation (MAP) for the 48-year record was 613 mm while the Mean Annual A-Pan equivalent Evaporation (MAE) is more than twice the MAP at 1 318 mm. Rainfall exceeds potential evaporation in only three months of the year, on average.

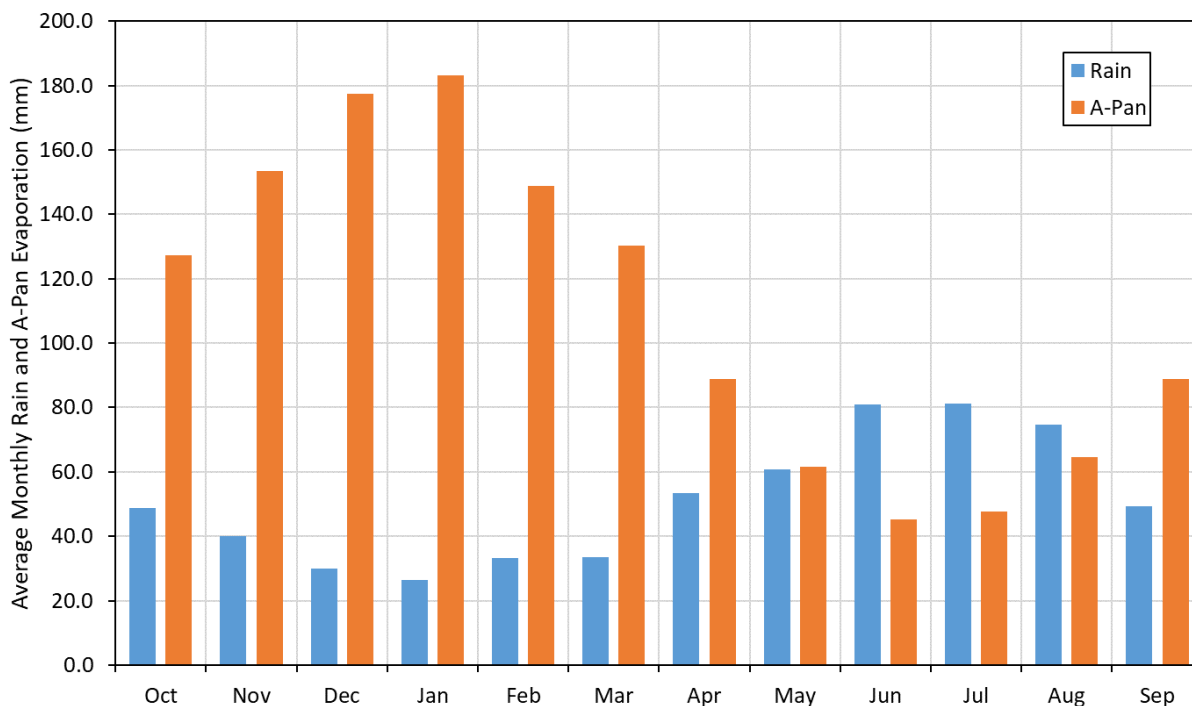


Figure 3-4: Onrus catchment average monthly rain and estimated A-Pan evaporation.

3.7 Gauged Runoff

A DWS gauging weir, G4H033, is located in the Onrus river in the upper portion of the catchment (Figure 3-5). The sub-catchment area contributing to the weir comprises 42% of the total catchment area.

The weir spans the Onrus river section, where water level measurements are made automatically upstream of the broad crested control (Figure 3-6). The record of daily observed flows was extracted from the DWS site for the period 01-May-1997 – 26-Sept-2023. The daily record is presented in Figure 3-7, where periods of missing record are indicated in the early part of the record.

An abrupt change in the flow regime is noted in the data, occurring in April 1993. A cumulative plot of the recorded flows, together with the cumulative daily rainfall illustrates this change as a significant flattening of the cumulative discharge data slope after 1993, with no concurrent change in slope to the cumulative rainfall (Figure 3-8). These differences in flow regime are further illustrated in Flow Exceedance plots in Chapter 5 (Figure 5-4 Top). It seems evident that low flows are particularly reduced post 1993.

The Mean Annual Runoff (MAR) of continuous record before 1993 is some 20 Mm³/annum, omitting missing data, whereas post 1993 up to 2023, the MAR is only 7 Mm³/annum. (Table 3-1).

Selected wet and dry periods post-1993, lasting more than 4 continuous years, report MARs of 13.9 Mm³/annum for the wettest period (April 2005 to December 2009) and as low as 2.7 Mm³/annum for the driest period (October 2015 to June 2020).

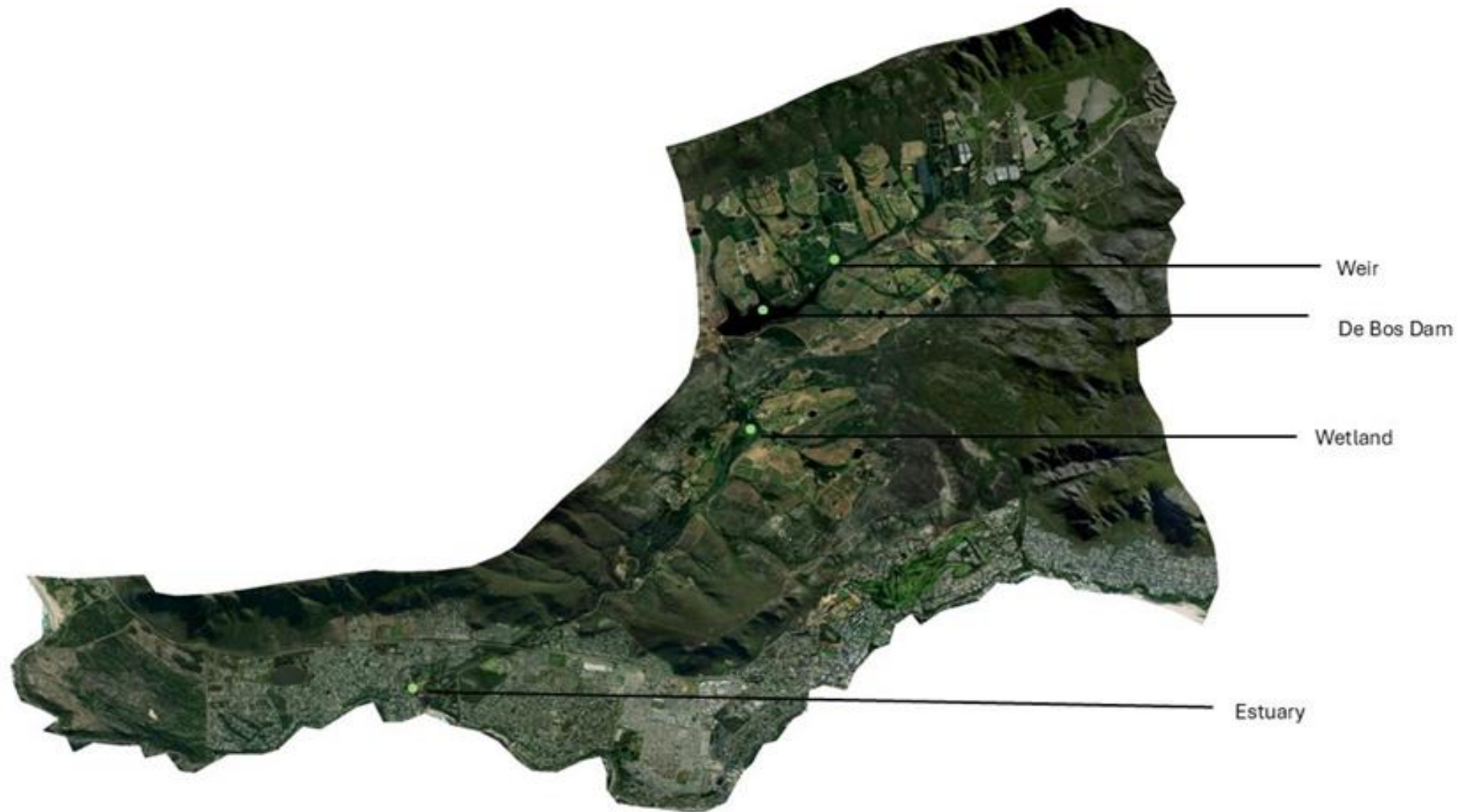


Figure 3-5: Onrus catchment showing locations of the Weir, Dam, Wetland and Estuary.



Figure 3-6: Weir G4H033 on the Onrus river, upstream of the de Bos dam inlet (20 July 2024).

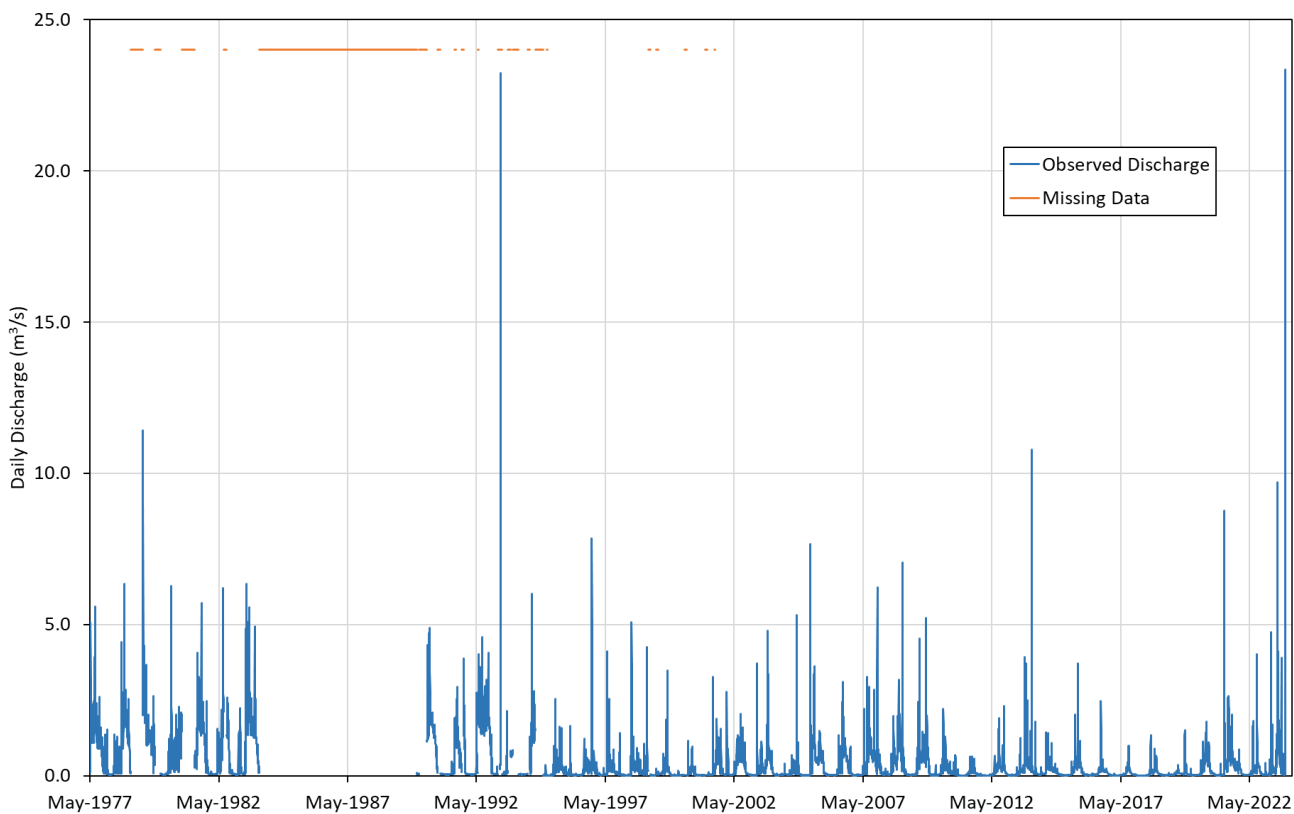


Figure 3-7: Daily discharge at the G4H033 weir.

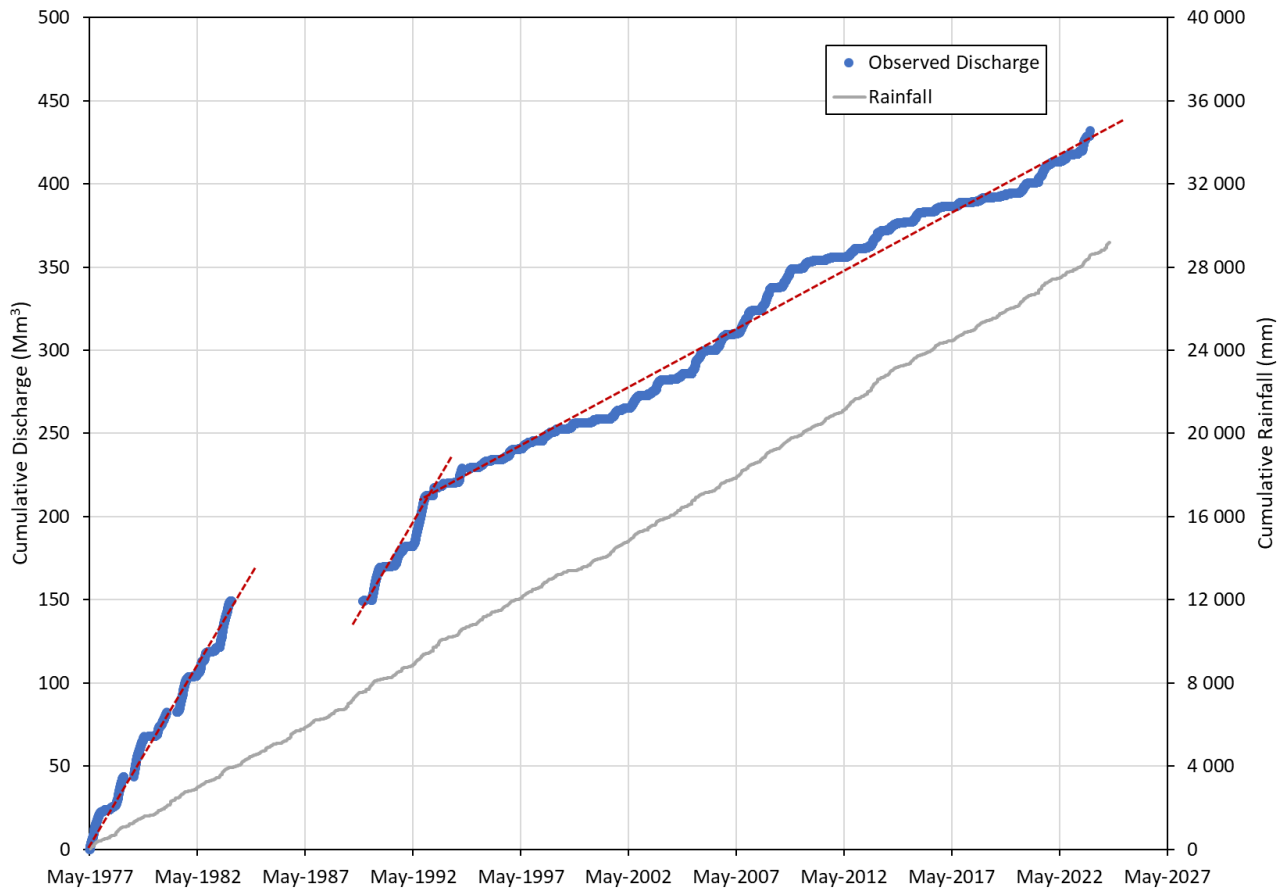


Figure 3-8: Cumulative discharge (G4H033) and cumulative rainfall 1977 – 2024.

Table 3-1: Summary of Mean Annual Runoff (MAR) recorded at G4H033.

Record From: To:	Cumulative Discharge (Mm³)	MAR (Mm³/a)	Duration (Years)	Missing Record (%)
01-May-77	0			
30-Nov-83	149.19	22.7	6.6	19.5%
29-Jun-90	154.16			
14-Dec-93	219.96	19.0	3.5	26.3%
14-Dec-93	219.96			
08-Sep-23	428.87	7.0	29.7	2.8%
Dry period				
09-Oct-15	382.05			
11-Jun-20	394.59	2.7	4.7	0.0%
Wet period				
03-Apr-05	285.94			
22-Dec-09	348.79	13.3	4.7	0.0%

The dramatic change in MAR between pre-1993 and post-1993 periods could be due to a number of reasons, each of which worth verifying to extract the best value from the observed daily flows. These reasons may include:

- A significant change in land use and/or abstractions from the Onrus river upstream of the weir, post-April 1993.
- Differences in the rating curve used pre-April 1993 to that used post-April 1993.
- Slight damage to the weir crest was noted in the centre of the weir (see Figure 3-6). This may be sufficient to pass much of the low flows without inducing a measurable pond elevation above the general crest level.

Observed instantaneous (sub-daily) peak discharges were extracted from the DWS record and are ranked in Table 3-2. The highest recorded discharge was estimated as 84.2 m³/s during 25th September 2023. However, the actual discharge was probably higher than this as the value is reported as unreliable, indicating the capacity of the weir had probably been exceeded.

Table 3-2: Highest 10 recorded peak flow depths and discharges at G4H033.

Date	Time	Depth (m)	Discharge (m ³ /s)
25-Sep-23	00:00	1.863*	84.2*
13-Apr-93	04:48	1.349	42.6
30-May-23	23:00	1.276	37.9
25-May-79	00:12	1.110	28.0
11-Apr-05	09:00	0.868	16.1
23-Oct-96	06:18	0.862	15.9
17-Nov-13	04:24	0.848	15.3
06-Mar-23	04:48	0.798	13.2
12-Oct-09	19:48	0.786	12.7
26-May-83	18:42	0.772	12.2

Note: * measurement unreliable

4 Alien Invasion Assessment

Invasion of alien species into the Onrus catchment has occurred predominantly along the stream systems. This generally occurs due to the conveyance of seed along the stream systems and opportune soil moisture along the banks for establishment. The proliferation of aliens in the catchment is undesirable, since:

- Alien species are likely to take up water and transpire at a greater rate than indigenous vegetation, hence reducing the catchment runoff.
- Aliens like eucalypts are likely to take up excessive soil water and leaf cover shields the ground surface, inhibiting growth in the understorey. This impacts the stability of the stream banks, which are vulnerable to erosion.
- Alien species are detrimental to the local ecology, particularly disrupting upland to riparian ecosystem corridors.

For these reasons recent alien species proliferation has been assessed.

4.1 Alien mapping

Mapping of the alien species was accomplished using satellite imagery correlated to ground verifications through on-site photography and local expertise.

4.1.1 Data sets

The Level 2A data product from the Copernicus Sentinel-2 mission launched by the European Space Agency was accessed from the publicly- and freely- available Google Earth Engine (GEE) catalogue. The Sentinel-2 imagery has a spectral resolution of 13 bands, a temporal resolution of approximately 5 days, and a spatial resolution of 10 m (bands 2, 3, 4, and 8), 20 m (bands 5, 6, 7, 8A, 11 and 12) and 60 m (bands 1, 9 and 10), (Rebelo et al., 2021). Sentinel-2 is of particular value for vegetation classifications, having four bands in the Red Edge region (Rebelo et al., 2021). For this project, the median of the Sentinel-2 images at a 10 m spatial resolution was obtained for the data period, January to August for 2018, 2021 and 2024, to provide the average conditions for these years. Based on personal communication with the ARC together with geo-referenced site photos, guidance was provided on the type and basic locations of alien species identified in the field. This information was then used to guide the visual inspection and produce the alien invasive maps as detailed below.

4.1.2 Training data

Training data, as illustrated in Figure 4-1, were used to produce the classifications. During the visual inspections, efforts were made to achieve a reasonable spatial spread of points across the classes. As such, two broad Land Use Land Cover (LULCs) classes were identified, namely, "alien vegetation" (comprising eucalyptus species and some plantations) and "non-alien vegetation" including grassland, fynbos, and urban areas. For each LULC, 200 points were selected for use, yielding a total of 400 points for both classes (for model training [70%] and validation [30 %] of the classification accuracy) which were assumed to represent the spectral properties for each of these classes across the catchment. For each of the training and validation data points, covariates (a combination of the original bands and the vegetation indices derived from these bands) were used.

4.1.3 Classifications

Maps of the years 2018, 2021 and 2024 were developed based on two classification techniques. These were a Traditional technique assigning the LULCs as either alien or non-alien, and a Probability technique, which provides a likelihood of whether a pixel represents alien vegetation. The assessment of these two techniques is explained in detail in Appendix A.

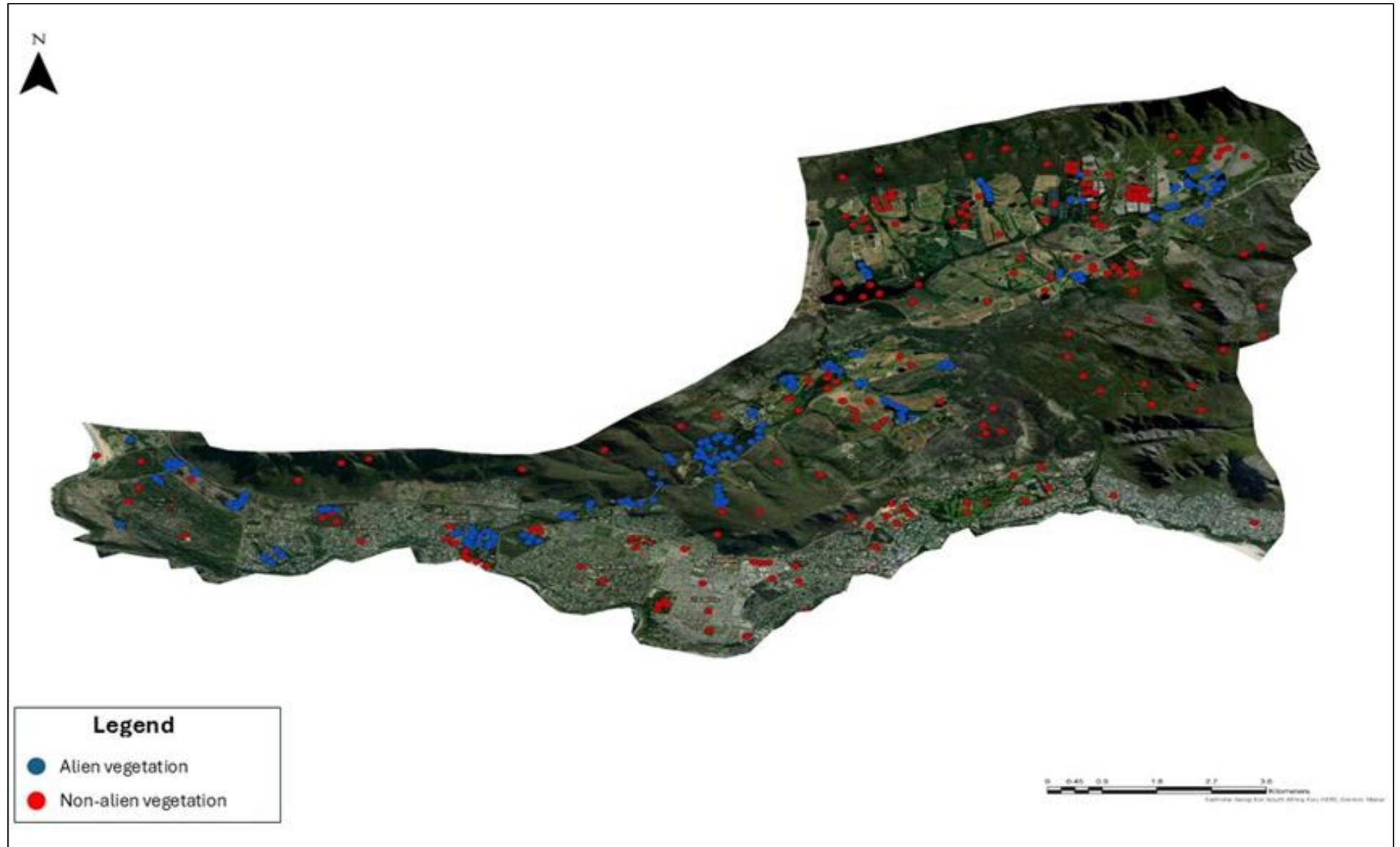


Figure 4-1: Onrus catchment showing Alien vegetation training points obtained through visual inspection, georeferenced site photos and local expertise.

4.2 Results

The distribution of alien vegetation is shown for the Traditional technique in Figure 4-2 for the three years, and in for the Probability technique in Figure 4-3. Two features are immediately apparent. The first is the predominant occurrence of alien vegetation along the drainage features and the second is the dramatic increase in alien vegetation over the 6-year period.

The alien infestation increases 10-fold over the 6-year period between 2018 to 2024, from 0.82 km² in 2018 to 8.6 km² in 2024 (Table 4-1). The current (2024) alien coverage is estimated to comprise 15.7% of the total Onrus catchment area.

Table 4-1: Summary of Alien Invasion extent.

Year	Alien Cover (km ²)	Percent of Catchment (%)
2018	0.82	1.5%
2021	5.31	9.7%
2024	8.61	15.7%

The overall accuracy of the alien coverage estimates derived from the Traditional technique is 93.3%. The accuracy of the Probability method is measured using a characteristic defining the ability of the classifier to distinguish between the classes. The characteristic, AUC-ROC, varies from 0 to 1, where the higher the value, the better the model distinguishes between aliens and non-aliens. The AUC-ROC characteristic value for the Probability technique was 0,99, indicating good differentiation of the two vegetation types. (Detail is presented in Appendix A).

Subsequent to the production of these alien distribution maps, the Agricultural Research Council has produced land-use maps which include alien species. This product may further enhance the estimates made in this study, (2024 ARC coverage Cape Farm Mapper: <https://gis.elsenburg.com/apps/cfm/> under resource layers).

The alien coverage has been used in the simulation modelling of the daily hydrology in the Onrus catchment. However, since the area is still small (15.7%) compared to the whole catchment area, the reduction in runoff caused by the riparian is not large. A fictitious scenario has been generated, where significant further infestation of aliens is included, to illustrate possible reductions in discharge (Chapter 5).

However, the effects of the alien species on runoff generation could be improved with detailed mapping (georeferenced drone photography) and in-situ ground truth observations. Further improvements could be made by incorporating measured alien species uptake rates in the model parameterisation.

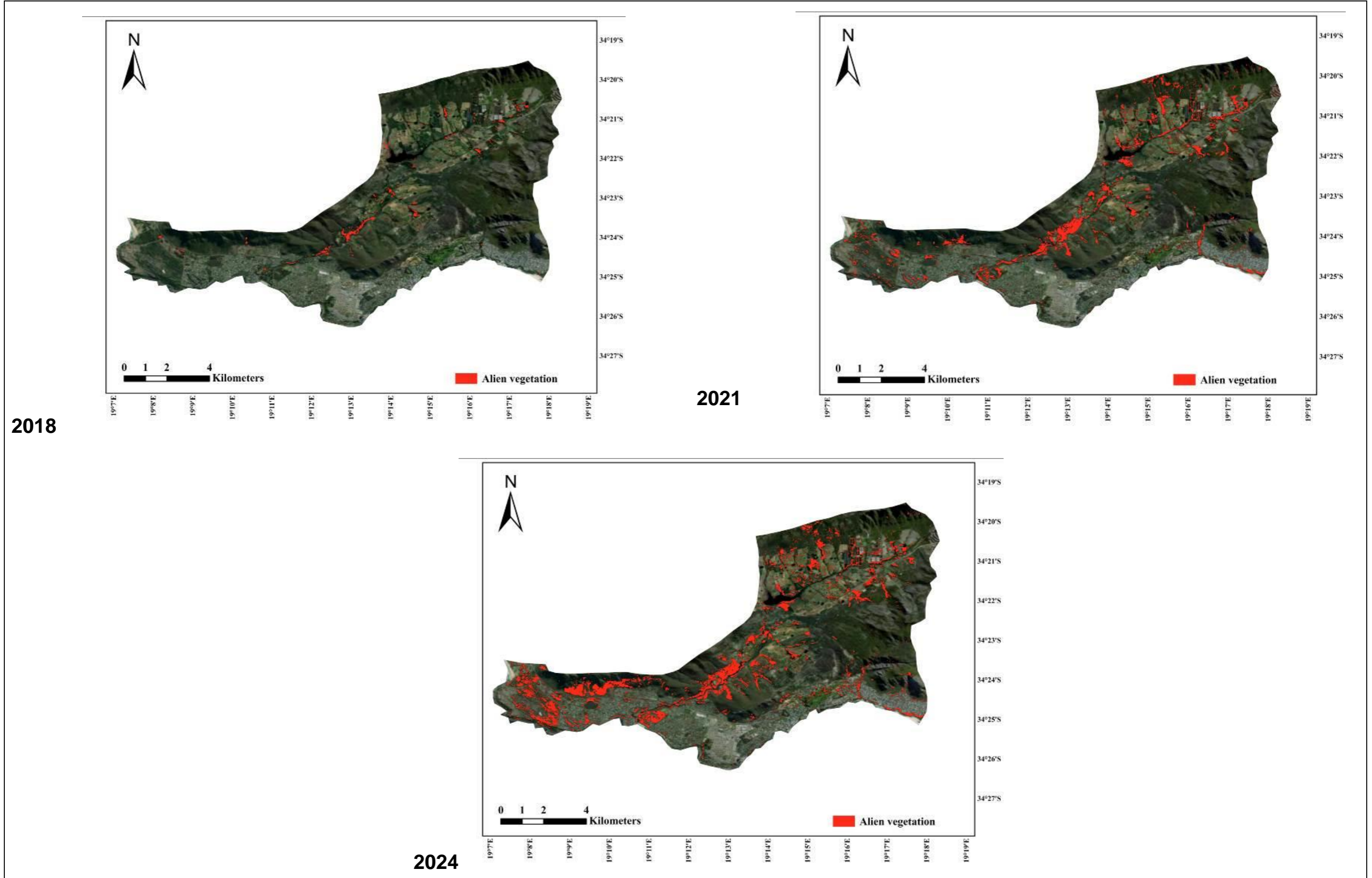


Figure 4-2: Extent of Alien Vegetation for 2018, 2021 and 2024 (Traditional classification technique).

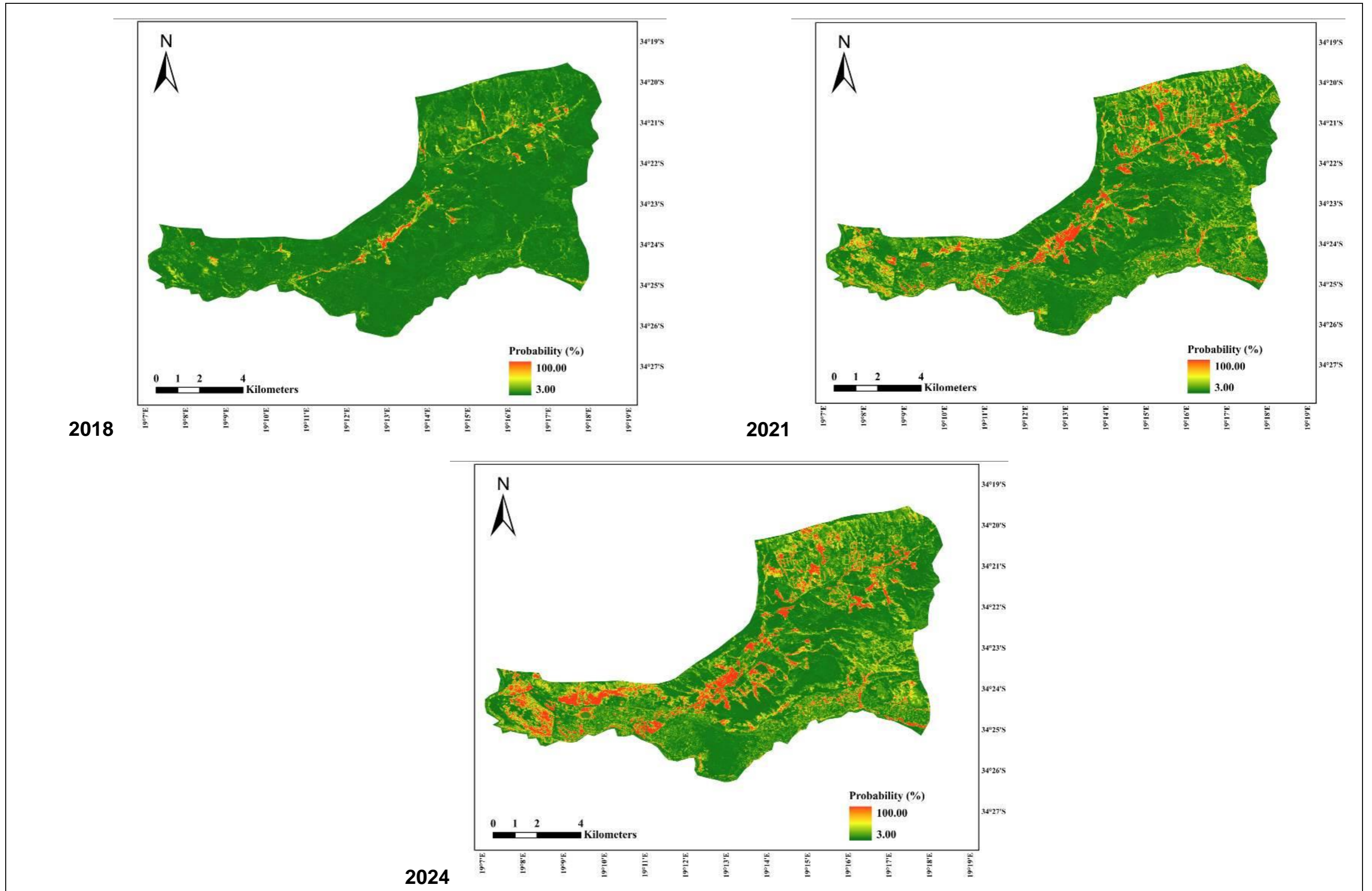


Figure 4-3: Extent of Alien Vegetation for 2018, 2021 and 2024 (Probability classification technique).

5 Hydrology Simulations

The simulation of runoff in the Onrus catchment required a hydrological model that could be used to check against daily measured flows as well as include the impact of land-use changes on the runoff. Accordingly, the ACRU agro-hydrological model (Schulze, 1986; Schulze, 1995; Smithers and Schulze, 1995; Schulze and Davis, 2018 and updates) was selected due to: its physical conceptual nature; being a model developed in South Africa; already being used in the South African water sector; appropriate for modelling at the meso-catchment or quaternary catchment scale, as needed for most water resource management applications and supported by a range of South African derived input datasets.

The ACRU model is a daily physical conceptual model, which determines the natural daily fluctuations in the water balance of the climate/plant/soil continuum and ensures internal consistency through the feedforward and feedback between the various components of the hydrological system (Figure 5-1). As such, it allows for assessments of land use changes, and subsequent impacts on water resources. The ACRU modelling system also allows users to build models that are discretised at the scale of sub-catchments or to further discretise sub-catchments into Hydrological Response Units (HRUs). The HRUs typically represent unique vegetation, land use and soil combinations.

Whilst stormflow is generated in response to daily rainfall, it does not all leave the catchment on the same day, as the model allows for a lag to be created between the stormflow that is generated and the stormflow leaving the catchment (Department of Environmental Affairs and Development Planning, 2021). Baseflow contributions are similarly delayed in response to groundwater accumulations. The vegetation type, soil type and land cover are used in the model to best represent the soil water budget (Department of Environmental Affairs and Development Planning, 2021) by considering factors such as canopy interception, water use by the vegetation type, amount of litter on the surface, and rooting depth distributions, due to its influence on transpiration and subsequent water yield (Schulze et al., 1995).

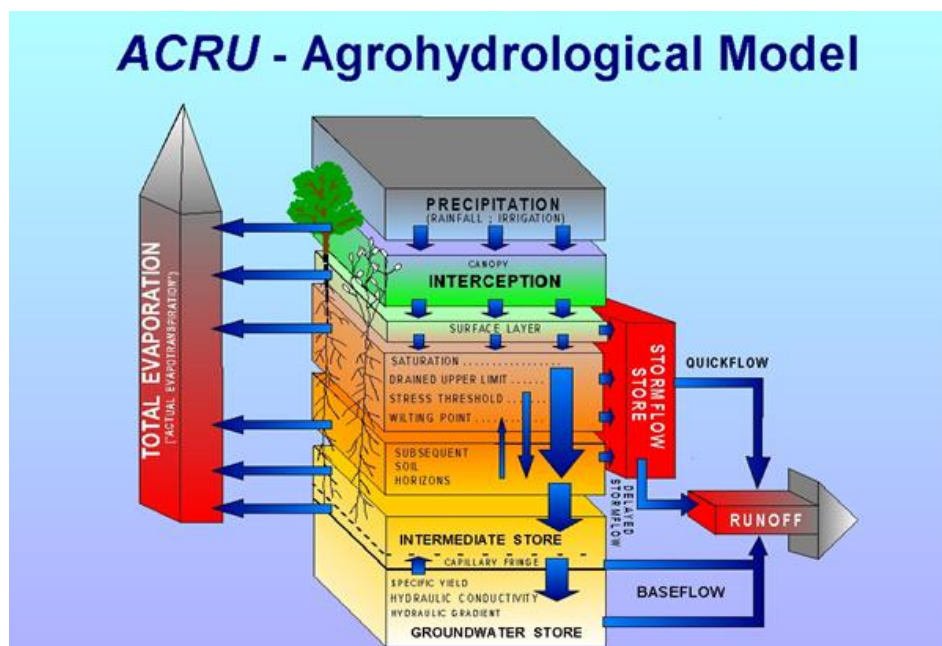


Figure 5-1: Schematic representation of the hydrological processes in the ACRU Model (Schulze 1995)

5.1 Model Set-Up

The Onrus catchment area, previously delineated from the Quaternary G40H was further delineated into three major sub-catchments as illustrated in Figure 5-2. These sub-catchments, delineated using a DEM, (Weepener, et al., 2011), were based on key point on the Onrus river as follows:

- **Sub-catchment 1:** accounts for the inflow and outflow from the de Bos dam.
- **Sub-catchment 2:** accounts for discharge generated between the de Bos dam outlet and the outlet of the wetland.
- **Sub-catchment 3:** accounts for discharge generated between the Wetland outlet and the Estuary.

The discharges in the Onrus river are reported as the cumulative flows at these positions for all contributions upstream of the position.

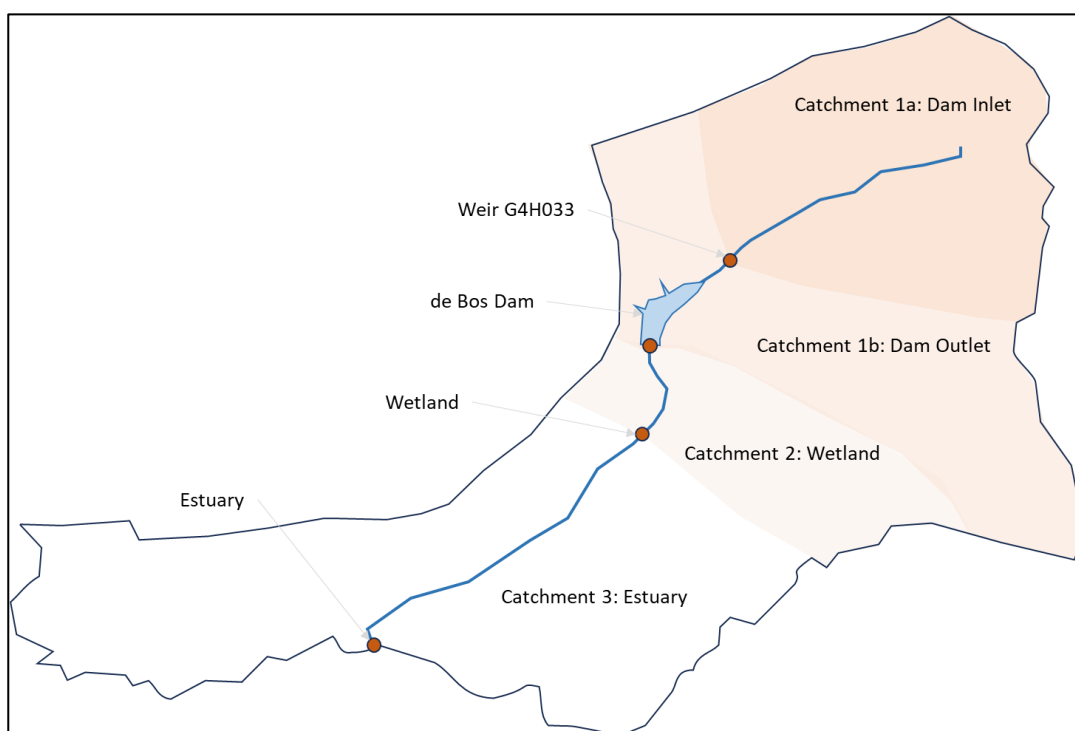


Figure 5-2: Onrus catchment, illustrating the regions simulated in the ACRU model.

Each sub-catchment was further characterized using the following assumptions:

- All the smaller dams (including individual farm dams) were combined with the de Bos dam as one lumped dam, by summing the individual surface areas and volumes.
- The de Bos dam operations and its characteristics as well as the environmental flow releases were obtained from a report by the Department of Water Affairs and Forestry, (2004). These included the dam capacity of 6,3 million m³ and compensation releases of approximately 0.5 million m³/a to supply irrigators and urban use downstream of the dam.
- The de Bos Dam evaporation rates were calculated using climatic data and reference evapotranspiration using the Hargreaves and Samani 1985 method.
- Climate data (to represent daily temperature, rainfall, and reference ET) used for the catchments was derived from the national Quinary catchment database (Maherry et al., 2013)

for the period 1950-1999, whereas, for the period 1999-2023, temperature and rainfall was obtained from ERA5 (Copernicus Climate Change Service, Climate Data Store, 2021) and checked against observed rainfall records, and reference ET was obtained from WaPOR (FAO 2018; 2020) global datasets.

- Topography and delineation of catchments was done using elevation data from the Digital Elevation Model (DEM) (Weepener et al., 2011) for South Africa from the 30m DEM resolution Shuttle Radar Topography Mission (SRTM).
- Soils data were extracted from the National land type manuals, obtained from the Land Type Survey Staff (developed by the Agricultural Research Council 's Institute for Soil, Climate and Water) (ARC-ISCW) to determine the soil parameters to be input into the model.
- Land use data was obtained from the updated dataset of the 2022 South African National Land Cover NLC data (1990-2022) with a 30 m resolution and includes 73 land cover/use classes. The model vegetation parameters were extracted from parameter listings against these vegetation types.
- The simulation of daily runoff was curtailed to 1993 to 2024, to coincide with the recent observed record for calibration purposes, but the 1977-2024 rain data were used in scenario simulation.

5.2 Calibration

The daily simulated runoff at the de Bos dam inlet position, (being the location of the measurement weir, G4H033), using current land use, was compared to the observed values for the period 1993 to 2024. Small adjustments to the evapotranspiration and soils parameters were made until a best-fit simulation was achieved.

This upper portion of the Onrus catchment comprises 42% of the total catchment, but the main hydrological parameters (other than vegetation and soils parameters) were retained for simulating the lower two sub-catchments. Further simulation scenarios included Natural vegetation types without dams, irrigation abstractions or alien species, and other fictitious scenarios assuming changes in irrigation and alien distribution.

5.3 Simulation Scenarios

Six land use scenarios were simulated as described below. The simulated configurations are illustrated in Appendix B.

5.3.1 Scenario V1: Natural Veld Types

The baseline hydrology was simulated with natural vegetation parameters derived from Acocks, 1988, vegetation /veld types.

5.3.2 Scenario V2: Current Land Use

Parameters for the Current Scenario were derived from the National Land Cover, 2022 map. This scenario also included:

- All farm dams were combined with the de Bos Dam as one lumped dam, by summing the individual surface areas and volumes.
- The de Bos Dam operations and its characteristics as well as the environmental flow releases were obtained from a report by the Department of Water Affairs and Forestry, (2004). These included the dam capacity of 6.3 million m³ and compensation releases of approximately 0.5 million m³/a to supply irrigators downstream of the dam

- The de Bos Dam evaporation rates were calculated using climatic data and reference evapotranspiration using the Hargreaves and Samani method.

5.3.3 Scenario V3: Current Land Use with 50% of Fynbos invaded by Aliens

In this scenario 50% of the current Fynbos land use is converted to Alien infestation. All other current land use, dams and abstractions are retained.

5.3.4 Scenario V4: Current Land Use without Irrigation

This scenario includes current land use, including current alien distribution, but the irrigation abstraction from the de Bos dam has been removed.

5.3.5 Scenario V5: Current Land Use without Aliens

This scenario includes the current land use with current irrigation abstractions but assumes all alien vegetation has been removed and re-established with fynbos.

5.3.6 Scenario V6: Current Land Use without Aliens and without Irrigation

This scenario includes the current land use without irrigation abstractions and assumes all alien vegetation has been removed and re-established with fynbos.

5.4 Simulation Results

5.4.1 Mean Annual Runoff

Although the simulation period provided 48 years of daily runoff, the long term Mean Annual Runoff is the first results worth evaluating. The simulated MARs, at each position on the Onrus river, are compared against the Natural vegetation land use simulation (Scenario V1), (Table 5-1).

At the upstream weir position, the Natural vegetation scenario has an MAR (9.4 Mm³/a) some 34% higher than the past 30 years of measured flows (7.0 Mm³/a – Table 3-1), which seems realistic, although it is nowhere near the flow rates recorded from 1977 to 1993 (20 Mm³/a).

Table 5-1: The Onrus catchment simulated Mean Annual Runoff (and % change at Estuary)

Scenario	Description	Dam Inlet	Dam Outlet	Wetland	Estuary	Change from Natural (%)
		(Mm ³ /a)	(Mm ³ /a)	(Mm ³ /a)	(Mm ³ /a)	
V1	Natural vegetation	9.4	9.4	12.0	13.9	0.0%
V2	Current Land Use	9.7	6.5	9.0	11.1	-20.2%
V3	Current Land Use, 50% of Fynbos = Alien	8.2	5.0	7.2	9.0	-35.3%
V4	Current Land Use without Irrigation	9.6	9.3	11.8	13.9	-0.2%
V5	Current Land Use without Aliens	9.7	6.6	9.1	11.1	-19.8%
V6	Current Land Use without Aliens or Irrigation	9.7	9.3	11.9	13.9	0.1%

The Current Land Use discharge at the weir is greater than the Natural cover, due to the increase in hard surfaces. However, the large reduction in simulated discharge at the Dam Outlet position. The Current Land Use Flows accumulate toward the Estuary, where the MAR is estimated to be 20% less than Natural.

Possible Alien infestation into 50% of the fynbos (V3), reduces the current MAR at the estuary by a further 15%.

Removing irrigation (V4) results in the Current Land Use discharges being close to the Natural scenario at estuary, even though the current alien coverage (15.7% of the total catchment area) is included in the Current scenario. The reduction in stream discharge due to aliens is offset by the increase in runoff from hard surfaces.

Without any aliens, (V5) the model predicts marginally more runoff than with the current alien distribution. This may be due to alien distributions on the steep slopes being replaced with grass vegetation, yielding slightly more runoff. However, it would be prudent to improve the model capability to simulate riparian alien uptake by including field observations of evapotranspiration from aliens. An improved definition of alien species distribution through field survey, would also allow for more accurate runoff perturbation predictions.

Current land use without any irrigation abstractions or alien vegetation (V6) results in a marginally higher runoff than the Natural scenario, again, due to the increase in hard surfaces.

5.4.2 Daily Runoff

The time series of simulated daily flows reflect similar results as the MAR, but some nuances are worth noting. The comparison of the time series of Natural condition flows (V1) and Current Land Use flows (V2) are illustrated for each position on the Onrus river in Figure 5-3. Above the de Bos dam, flows for the current scenario are generally lower than Natural conditions. However, some of the peak flows in the current condition exceed those of natural conditions, confirming that hard surfaces contribute to higher peak flows and possibly compensate for the generally reduced flows, resulting in a slightly higher MAR than the natural condition.

Below the dam, it is evident that some peak flows are significantly dampened due to available storage in the dam (see Outflow from de Bos Dam: May 1989 and May 2005). The available storage obviously due to irrigation abstractions and evaporation losses from the dam. No significant flow retardation was included in the simulation of the Wetland, but the results do include the significant peak discharge of September 2023.

A full set of daily runoff scenario comparisons is presented in Appendix C.

5.4.3 Runoff Regime

The distributions of flows in the Onrus river for the current and natural land use scenarios are illustrated in Figure 5-4, which shows the percentage of the time that different discharge rates are equalled or exceeded. A full record of the flow exceedance plots of all scenarios is presented in Appendix D.

The Weir flows pre-1993 and post-1993 have been included separately in the flow exceedance plot for the Dam Inlet position (Figure 5-4 Top). As reflected in the observed flows assessment (Chapter 3-7), these periods have significantly different MARs. The entire flow regime curve for the pre-1993 period falls above that of the post-1993. Differences are particularly excessive between the 5% and 65% exceedance flows as well as during low flows lower than 80% exceedance (20% of all flows). Here the flows during the post-1993 period reduce to less than 0.001 m³/s (86 m³/day) for 1% of the time. This could be due to any of the reasons described in Chapter 3-7.

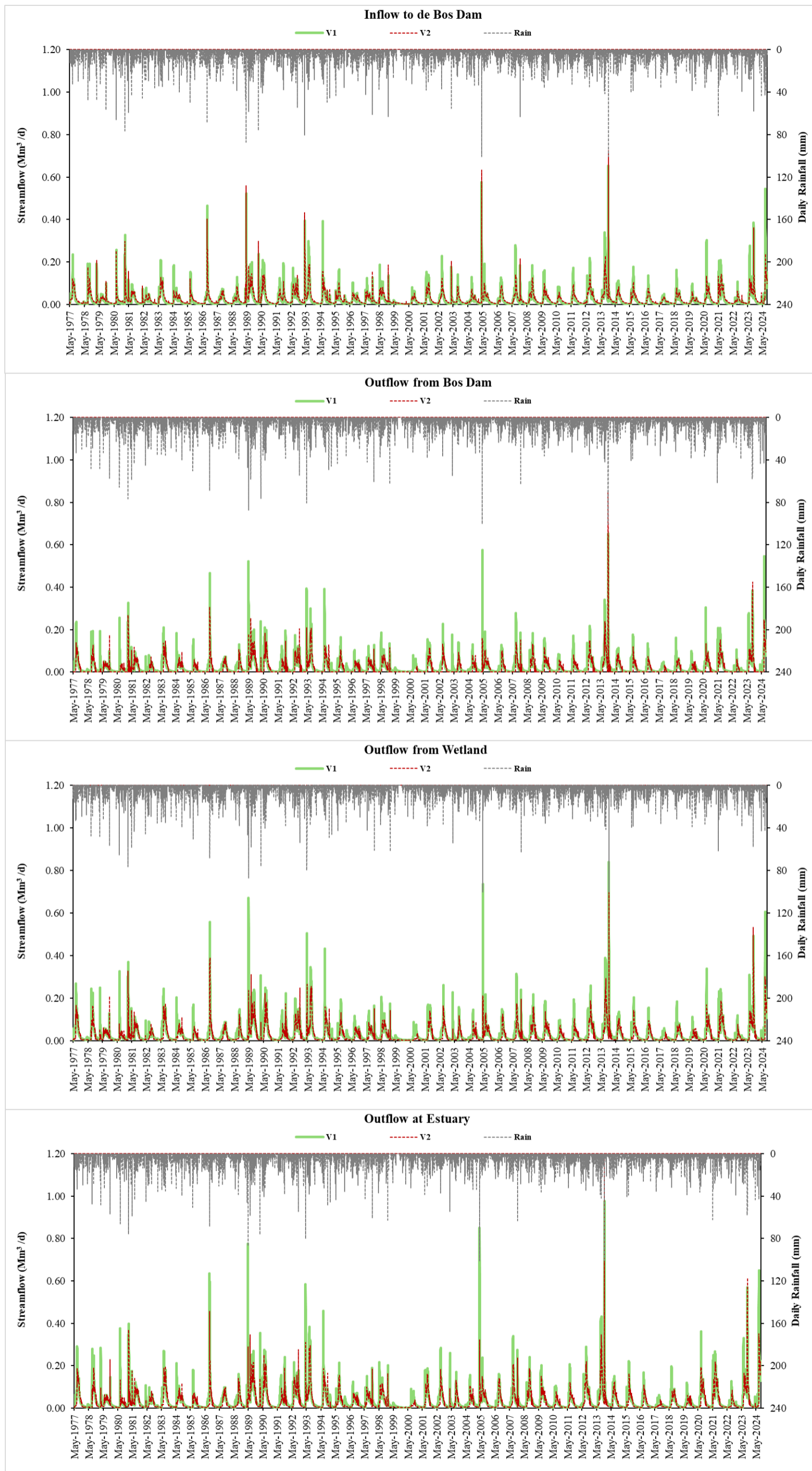


Figure 5-3: Daily time series of simulated Natural and Current Land Use at four locations in the Onrus catchment.

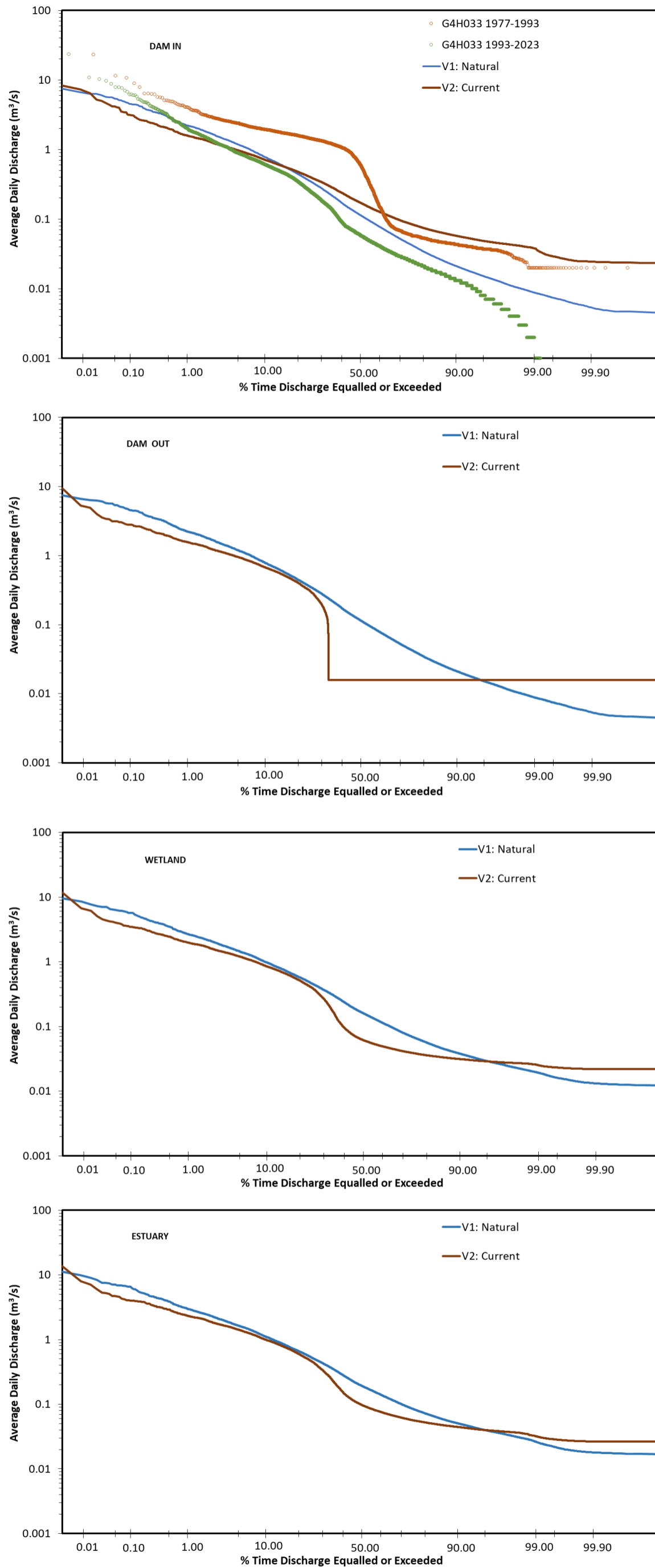


Figure 5-4: Simulated Flow Regimes at selected positions on the Onrus river.

The simulation of Natural vegetation results in a flow regime in between the pre- and post-1993 observed discharges (Figure 5-4 Top), including reasonable low flows down to 0.004 m³/s (350 m³/day).

The current land use (V2) simulated flows fall above those of the natural condition (V1) for all flows lower than the 15% exceedance value, while the highest flows (greater than 0.012% exceedance) are similar.

At the Dam Outlet position, the current flows depart significantly from the Natural scenario (V1) at the 20% exceedance value (Figure 5-4 Second from Top). The low flows at the 70% exceedance value of simulated current flows drops from 0.097 m³/s (8 400 m³/day) at the Dam Inlet to 0.004 m³/s (1 400 m³/day) below the dam.

This significant drop in discharge in the flow exceedance curve is progressively dampened towards the Estuary (Figure 5-4 Bottom two plots), where simulated low flows are 0.03 m³/s (2 600 m³/day)

5.4.4 Extreme Event Distributions

Peak discharge has been simulated in the ACRU model by applying the SCS algorithms for peak flow generation on a daily time step. This allows antecedent soil moisture conditions to be updated daily, so initial conditions for the daily peak flows are accurately represented. This exercise produces a 48-year set of daily peak flows which is subjected to Time Series Analysis to estimate extreme event flows for 10-, 20-, 50- and 100-year return intervals.

Design Floods were estimated using the Time Series Analysis tool within the ACRU4 modelling system. The Extreme Value Distribution option is used to fit probability distributions to the Annual Maximum Series (AMS) of peak discharges. L-moments (Hosking, 1990; Hosking, 1991) were used to fit the candidate distributions to the AMS. Different Extreme Value Distributions were calculated including, Log Normal (LN), normal distribution, log-Pearson-III (LP3), GEV and the Gumbel distribution. Each of these distributions can be used to predict design floods; and each method has their own advantages and disadvantages. Alexander (1990) recommends the LP3 distribution for South Africa. The Log-Pearson Type III was selected as the applicable technique to predict the design floods in the Onrus catchment.

Extreme value distributions are presented for the Current land use (V2) for positions at the de Bos dam inlet, the wetland outlet and the estuary in Figure 5-5. The peak flows generated only consider the portion of sub-catchment reporting to these positions and the upstream catchments are not routed through to downstream river sections. The estimated 1:100-year Return Interval (RI) event at the de Bos dam inlet is 120 m³/s, reflecting the rapid contributions of the steep hillslopes contributing runoff to the valley upstream of the dam. This exceeds the highest recorded discharge at the weir (84 m³/s) in September 2023, although the capacity of the weir was exceeded during this event. The sub-catchment contributing to the Wetland position yields a 1:100-year RI event of 41 m³/s, reflecting the smaller and flatter sub-catchment. The sub-catchment contributing to the Estuary position yields a 1:100-year RI event of 42 m³/s.

Future peak flows are likely to increase by 10 to 15% of those estimated here.

Similar Extreme Value Distributions for Scenarios V1 to V6 are presented in Appendix E.

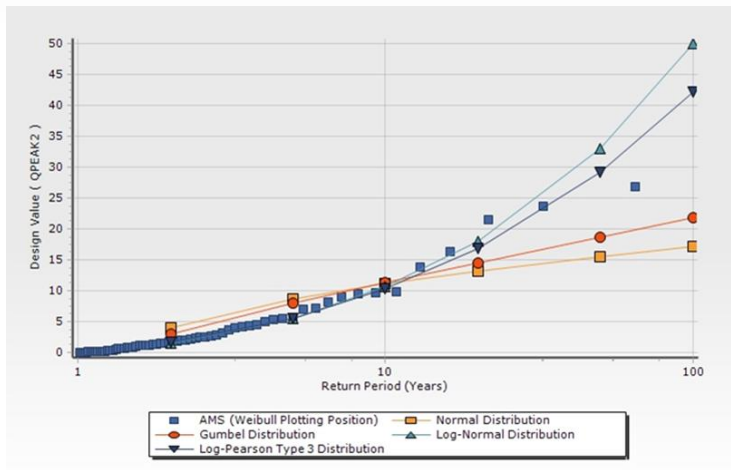
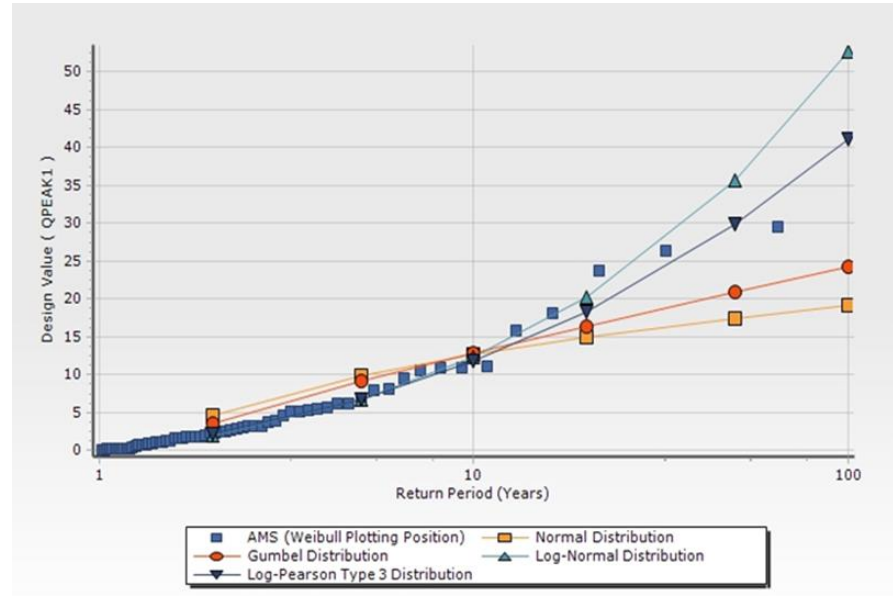
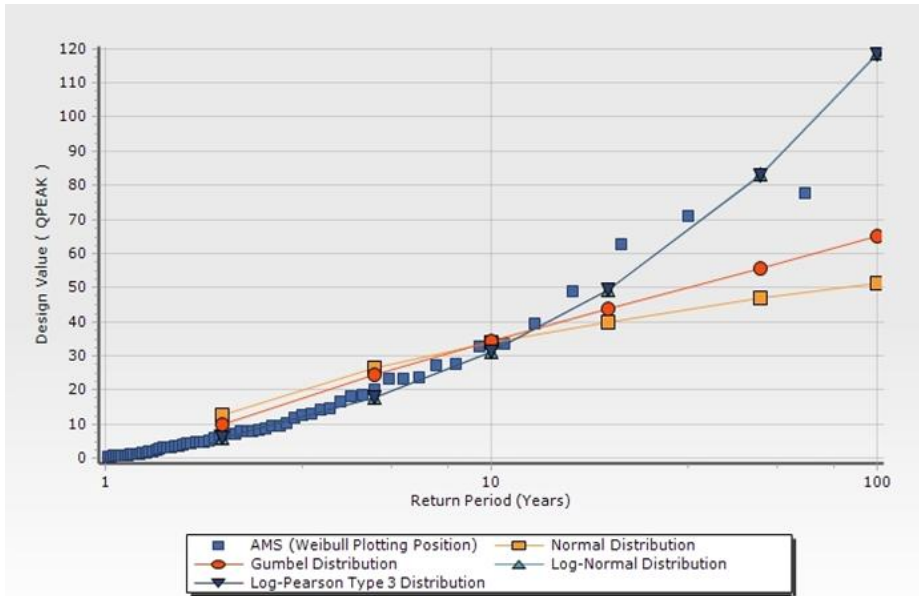


Figure 5-5: Extreme Value Distributions of peak flow (QPEAK: m³/s) for Current Conditions (V2) for the de Bos Dam Inlet (Top Left), Wetland (Top Right) and Estuary (Bottom Left)

5.4.5 Future Runoff

Estimates of future runoff have been made for all Quaternary catchments in South Africa by Schütte, et al., 2024, using the average outcomes of six GCMs (RCP8.5: Average of GCMs – Access 1-0; CCSM4; CNRM-CN5; GFDL-CM3; MPI-ESM-LR; NorESM1-M).

The results for Quaternary G40H which includes the Onrus river basin indicate a reduction in rainfall and increase in evapotranspiration, resulting in a 10 to 20% reduction in runoff in the near-future (2015-2044) and a 40 to 50% reduction in the distant-future (2070 to 2099), (Table 5-2). These estimates are based on natural vegetation conditions and do not account for potential future land use changes, impoundments or water abstractions.

Table 5-2: Summary of Climate Change predictions (Quaternary G40H) for Rainfall, Evapotranspiration (ET) and Runoff (Schütte et al., 2024).

Hydrological Parameter	Percent Reduction		Reduction or Increase Ratio	
	Present to Near Future	Present to Distant Future	Present/Near Future	Present/Distant Future
Median Rainfall			0.9 – 1.0	0.8 – 0.9
Median Potential ET			1.0 – 1.1	1.1 -1.2
Average Actual ET	< 5%	10 – 20%		
Runoff	10 – 20%	40 – 50%		

The model simulations in these previous sections are best considered as comparative assessments rather than absolute discharge predictions. Simulations can be improved by including:

- better definition of the alien species and their uptake characteristics,
- past, current and proposed de Bos dam release management,
- improved understanding of the runoff generation mechanisms in the catchment, particularly the hydrogeological responses and groundwater interactions,
- quantification of run-of river abstractions and
- a clearer understanding of the measured discharge at G4H033.

6 Conclusions and Recommendations

The following conclusions can be drawn from the hydrological assessment of the Onrus catchment:

- The full record of 47 years (1977 – 2023) of observed flows at the G4H033 weir has been assessed and nuances highlighted.
 - A very abrupt change in cumulative discharge is evident from April 1993 onward with the Mean Annual Runoff pre-April 1993 being some 20 Mm³/annum, and that post-April 1993 being 7.0 Mm³/annum.
 - The flow record post-April 1993 contains a period (more than four continuous years) of low flows averaging 2.7 Mm³/annum and a similar period of high flows averaging 13.3 Mm³/annum.
- Alien vegetation infestation into the catchment, mainly along water courses, has been determined using satellite imagery, colour band algorithms and *in-situ* observations.
 - The alien infestation has increased some ten-fold between 2018 and 2024. Aliens were estimated to cover 0.82 km² of the catchment in 2018 and 8.6 km² in 2024, being almost 16% of the total catchment area.
 - Increased alien infestation into 50% of the remaining current Fynbos in the catchment is simulated to likely reduce the catchment runoff by a further 15%.
- Simulated runoff of six land use scenarios revealed that:
 - The current land use, including current alien vegetation distribution and estimated irrigation abstractions results in a drop in runoff of 20% of natural vegetation land use.
 - Increases in alien infestation could easily cause a further 15% reduction in catchment runoff.
 - Removal of aliens and curtailing all irrigation abstractions could improve the average runoff yield by 35%.
- Extreme runoff estimates predict a 1:100-year Return Interval event in the upper catchment, upstream of the de Bos dam of 120 m³/s. due to the steep mountain slopes bordering the valley. Similar events contribute a peak flow from the catchment between the de Bos dam and the Wetland, of 41 m³/s, while the catchment between the Wetland and the Estuary produces 42 m³/s.
- Future Climate Change impacts on average annual and extreme events include:
 - A 10 to 20% decrease in average annual runoff in the near future (2015 to 2044) and a 40 to 50% decrease in the distant future (2070 to 2099).
 - A possible increase in extreme event discharge of 10 to 15%.

Based on the hydrological assessment, the following recommendations are offered:

The abrupt change in observed discharge in April 1993 needs to be investigated in terms of:

- Rating curve error
- Damage to the structure.
- Excessive upstream land use change and/or abstractions

The management of the de Bos dam and flow release requirements need to be confirmed to:

- Improve the prediction of flow regimes in the lower catchments.
- Allow for the simulation of alternate dam operation and release scenarios to be evaluated, including assessment of environmental flow releases.

Catchment runoff simulations need to be improved by:

- Better delineation and species identification of alien vegetation
- In-situ soils (hydropedological) and vegetation surveys
- Including observed alien species uptake and wetland mechanisms into the simulation model

The following monitoring needs to be installed:

- De Bos Dam outlet releases
- Any run-of-river abstractions
- A network of meteorological stations covering hillslopes and valleys

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Peter Shepherd
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All data used as source material plus the text, tables, figures, and attachments of this document have been reviewed and prepared in accordance with generally accepted professional engineering and environmental practices.

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Appendices

Appendix A: Alien Mapping Accuracy

A1 Alien Vegetation Coverage Accuracy Assessment

For validation, an independent validation dataset was generated by randomly splitting the training data into 70 % for training and 30 % for validation. The purpose of an accuracy assessment is to indicate the quality of information that is obtained from the remotely sensed data.

For the traditional classification technique, the performance of the RF classification algorithm was determined by comparing the overall accuracy (OA), user accuracy (UA), producer accuracy (PA) and kappa coefficient:

- **OA** is representative of the total classification accuracy and is calculated by dividing the total number of correctly classified pixels by the total number of reference pixels.
- **UA** refers to the probability that a pixel labelled as a certain class in the map is really this class. It is calculated by dividing the accurately classified pixels by the total number of pixels classified in this category.
- **PA** is the probability that a certain feature of an area on the ground is classified as such. It results from dividing the numbers of pixels correctly classified in each category by the number of sample pixels taken for this category.
- **kappa coefficient** refers to a discrete multivariate method of use in accuracy assessment. It provides a measure of how much better the classification performed in comparison to the probability of randomly assigning pixels to their correct categories. For example, A value of 0.60 indicates that the classification process was avoiding 60% of the errors that a completely random classification would generate.

For the probability classification technique, the performance of the RF classification algorithm was assessed by calculating the out-of-bag error, and the Area Under the Curve of the Receiver Operating Characteristic (AUC-ROC) statistics.

- **out-of-bag error** represents a method of measuring the accuracy of the RF classification algorithm.
- **AUC-ROC** assists with identifying how well the machine learning classifier is performing and refers to a measure of the ability of a classifier to distinguish between the classes. For example, the higher the AUC, the better the model's performance at distinguishing between the classes.

From the accuracy assessments of the two classification approaches that were taken (Table A1), both classifications performed fairly accurately in the validation of alien/non-alien vegetation classes. With the use of the traditional classification using the RF model, the LULC classification model achieved an OA of 93% and a kappa coefficient of 0.87. The average class-specific PA and UA for the RF classification were 93.34 % and 93.33 %. Both classes were predicted with similar accuracies.

Using the probability classification with the RF model, an out-of-bag error of 0.075 (values closer to zero represent greater accuracy) and an area under the curve receiver operating characteristics (AUC ROC) value of 0.99 (values closer to one represent more accuracy) was achieved. Hence, both results displayed accurate performance in mapping the classes.

Table A1 Accuracy results of the two classification techniques for the Onrus Catchment.

Accuracy Assessment			
Classification Technique:	Traditional		Probability
Classification algorithm:	RF		RF
Overall Accuracy (%):	93.33		Out-of-bag error: 0.075
Kappa coefficient:	0.87		AUC-ROC: 0.99
	PA (%)	UA (%)	
Alien Vegetation	93.93	92.54	
Non-alien vegetation	92.75	94.11	
Average	93.34	93.33	

Appendix B: Simulation Scenarios

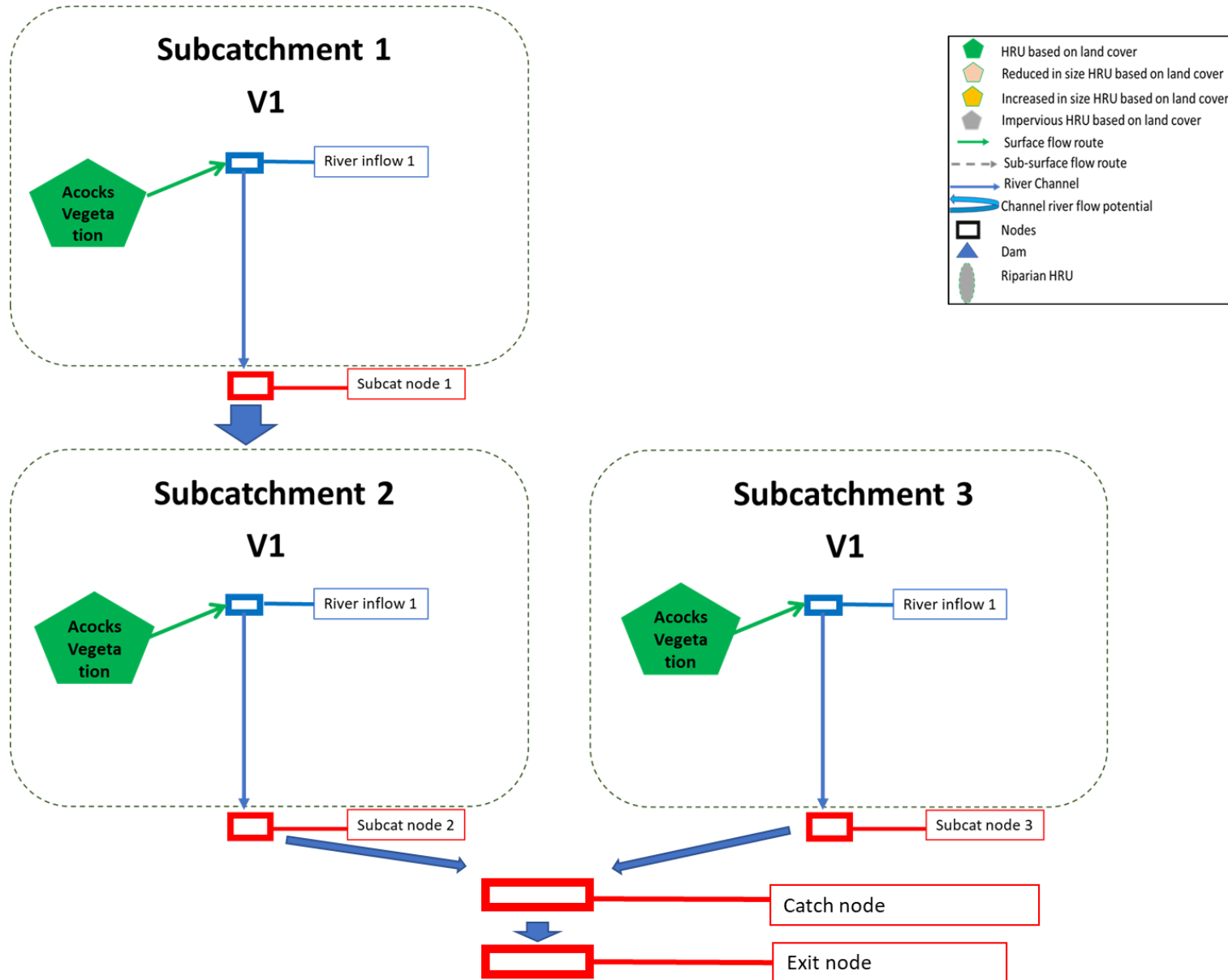


Figure B1: Scenario V1. Natural Acocks Land Use.

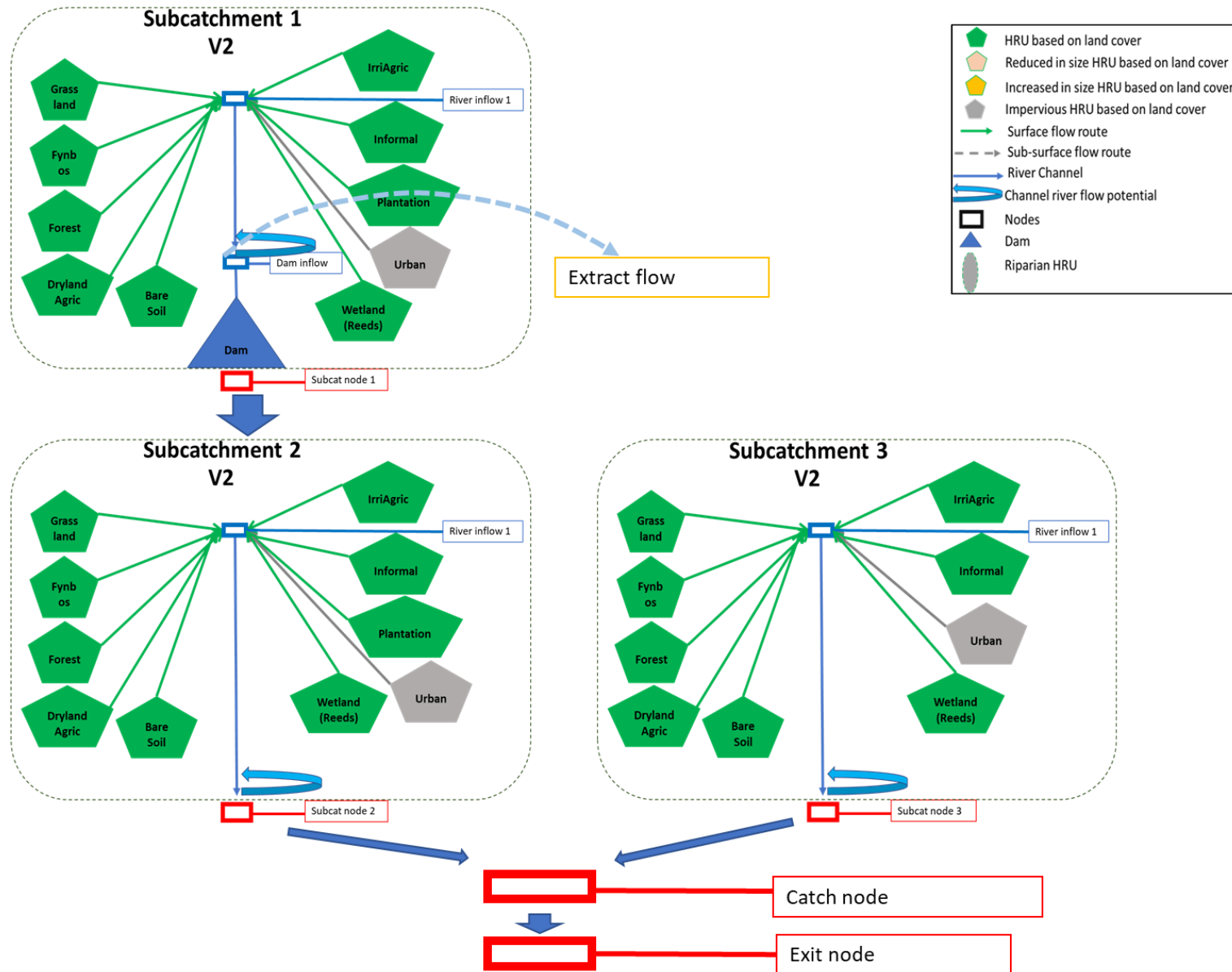


Figure B2: Scenario V2. Current Land Use, including current aliens and irrigation.

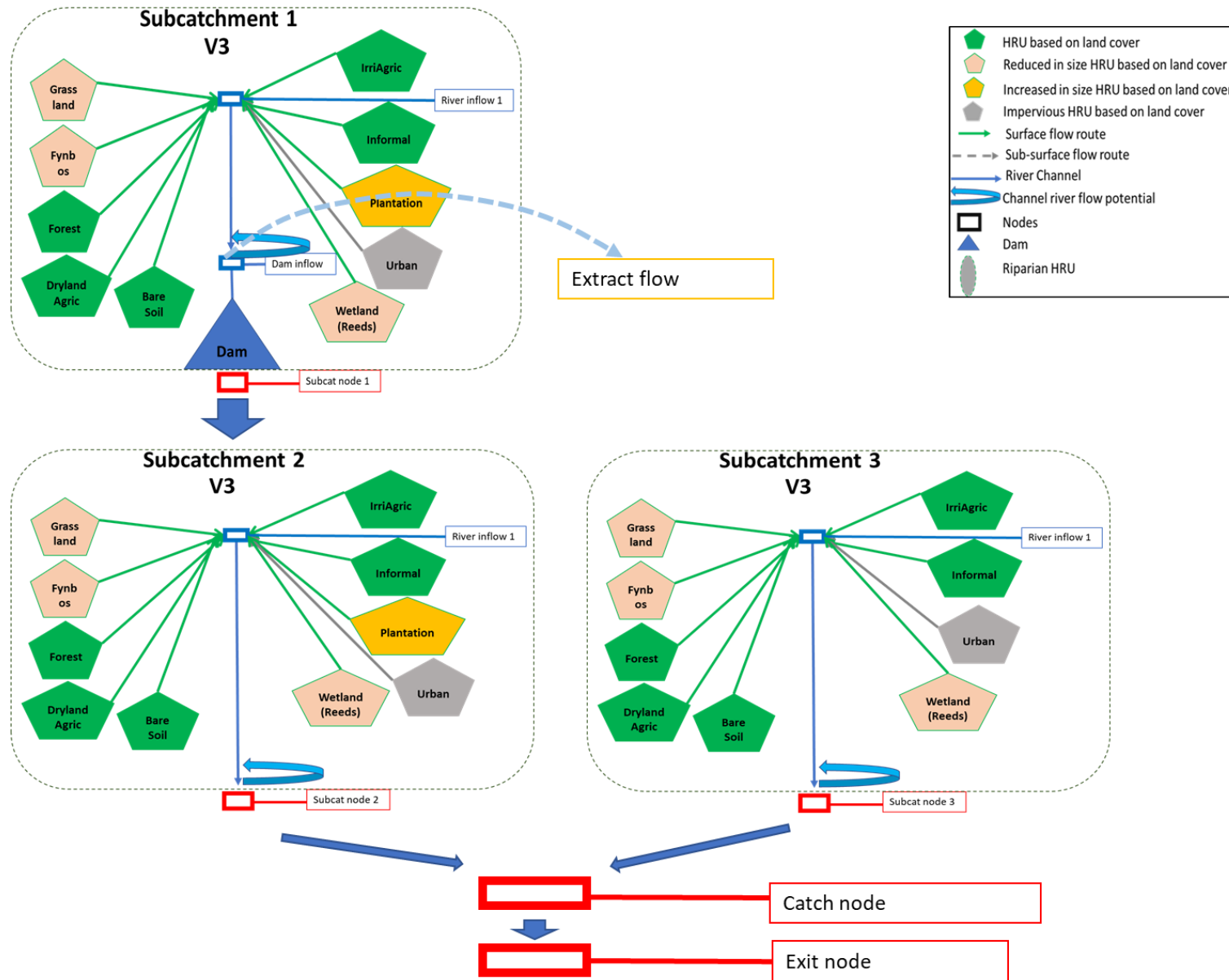


Figure B3: Scenario V3. Current Land Use and irrigation, with 50% of fynbos and wetlands invaded by aliens.

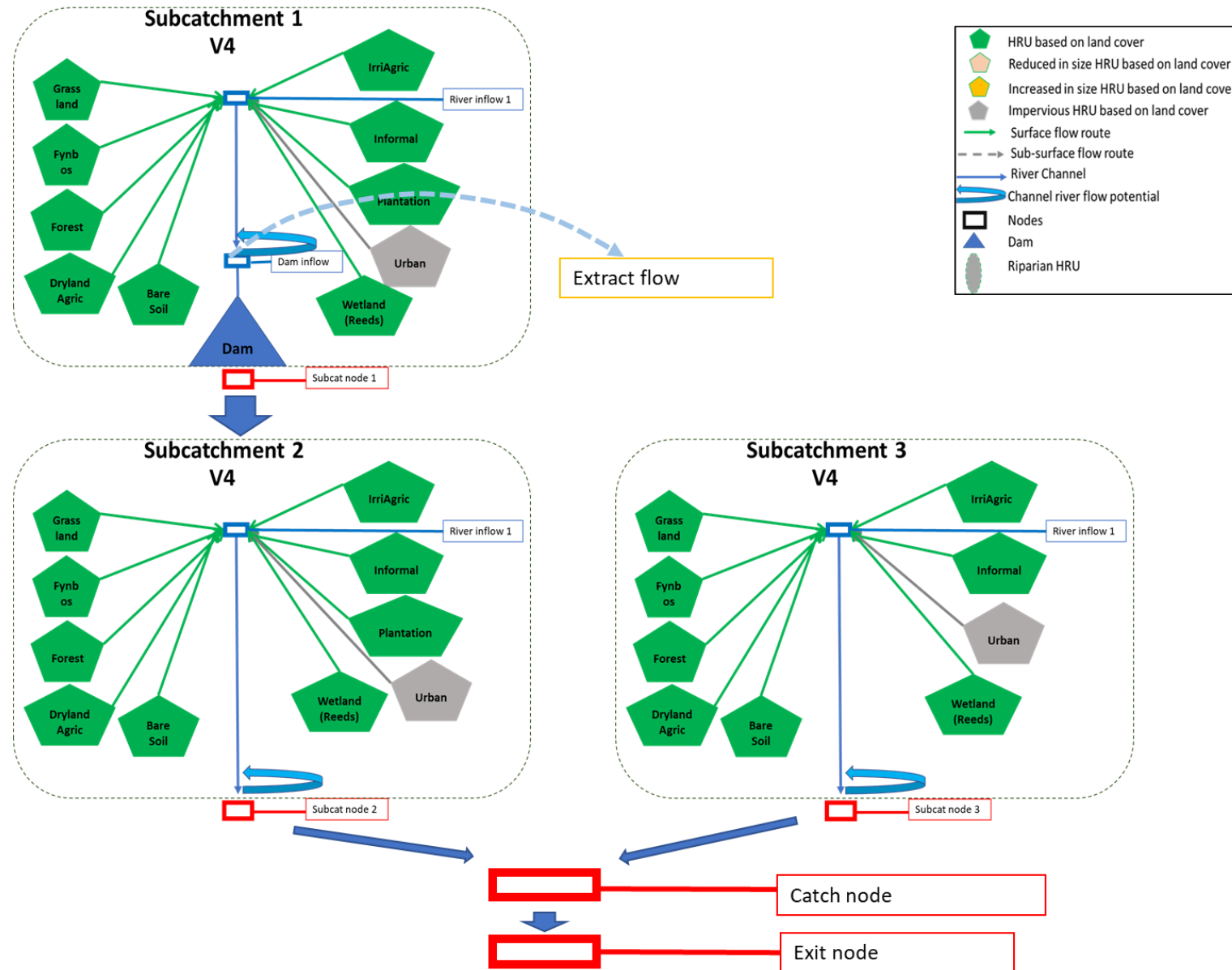


Figure B4: Scenario V4. Current Land Use and No irrigation, including current aliens.

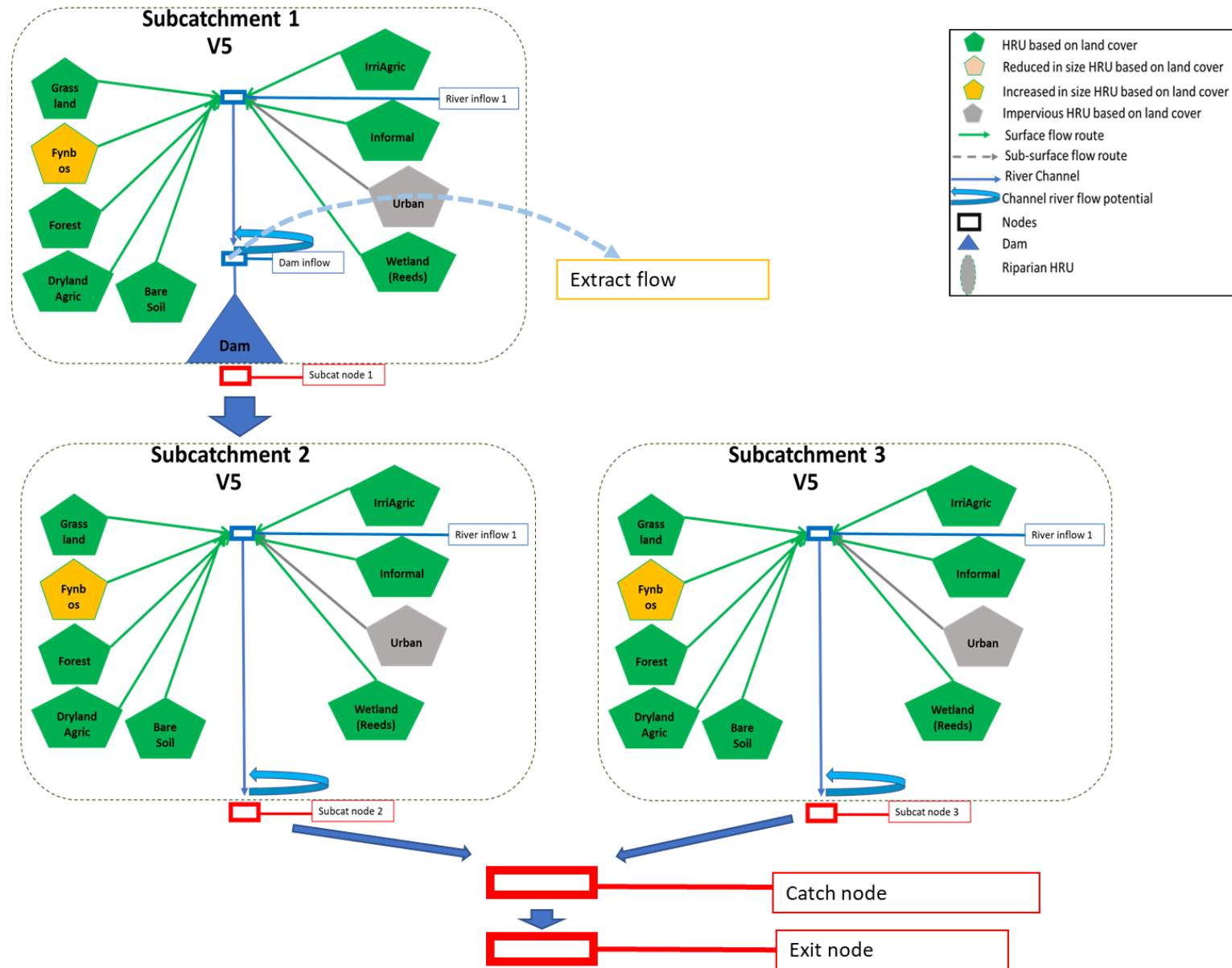


Figure B5: Scenario V5. Current Land Use and irrigation, all aliens replaced by fynbos.

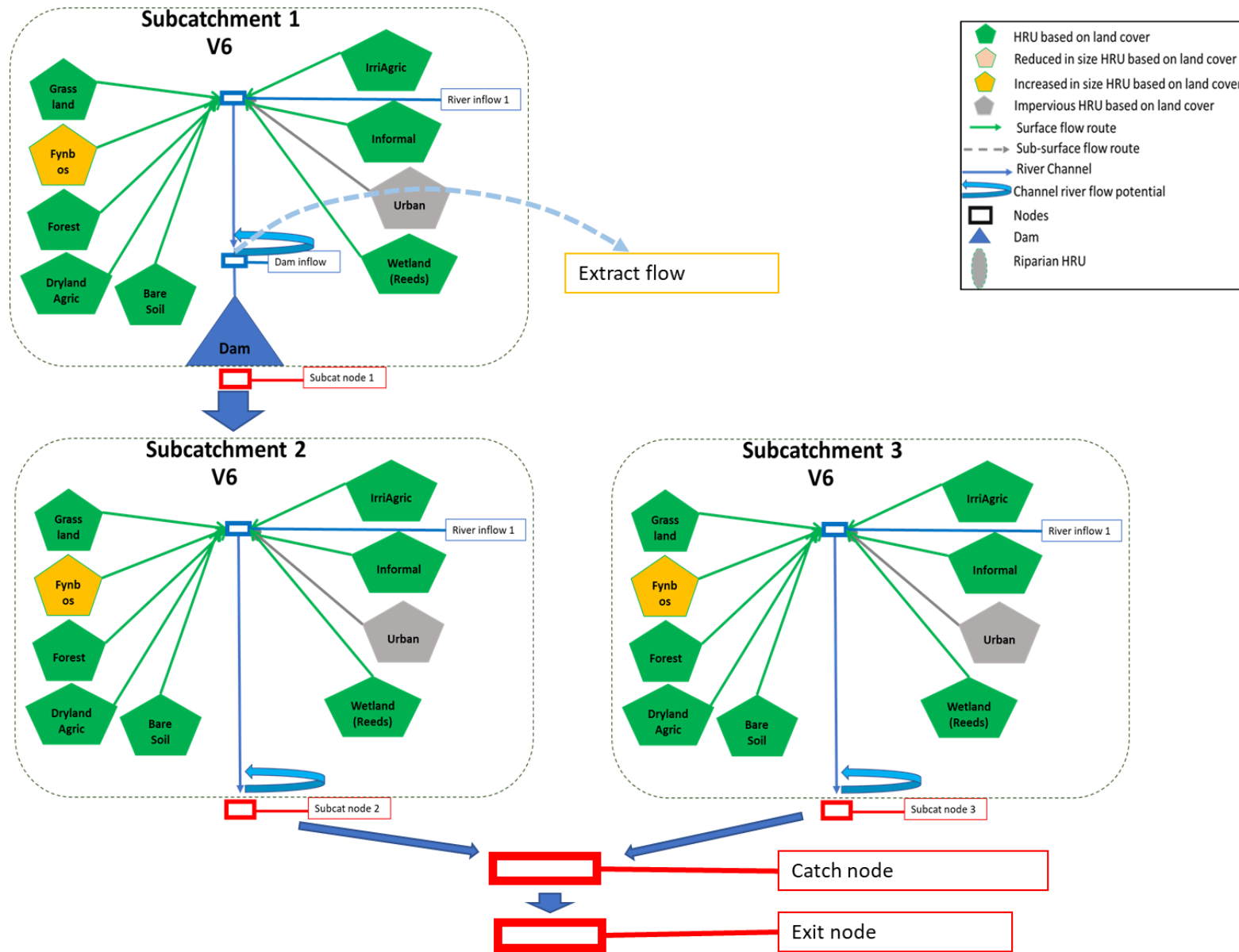


Figure B6: Scenario V6. Current Land Use without irrigation and all aliens replaced by fynbos.

Appendix C: Simulated Daily Time Series

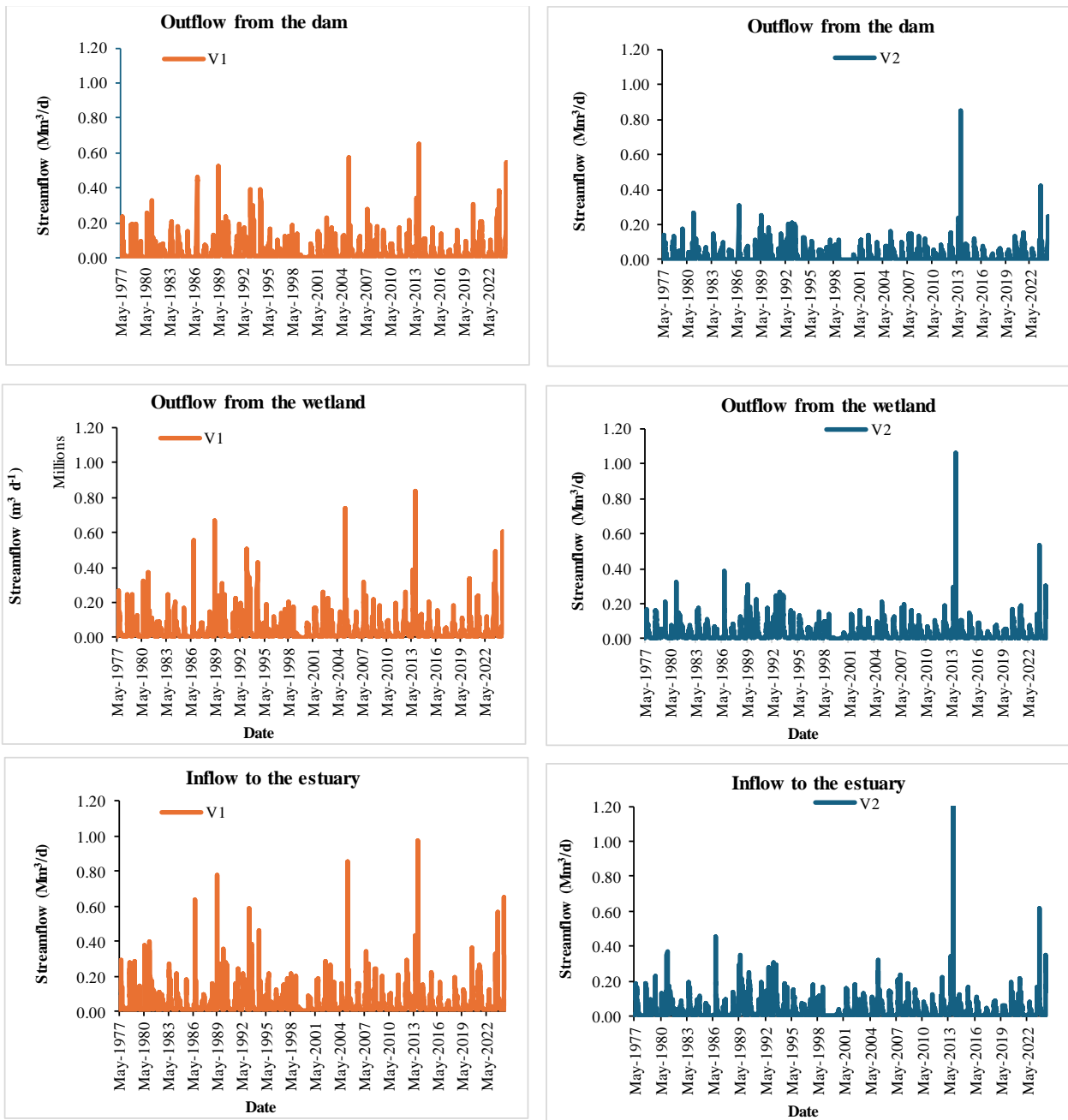


Figure C1: Simulated Scenario V1 compared to V2.

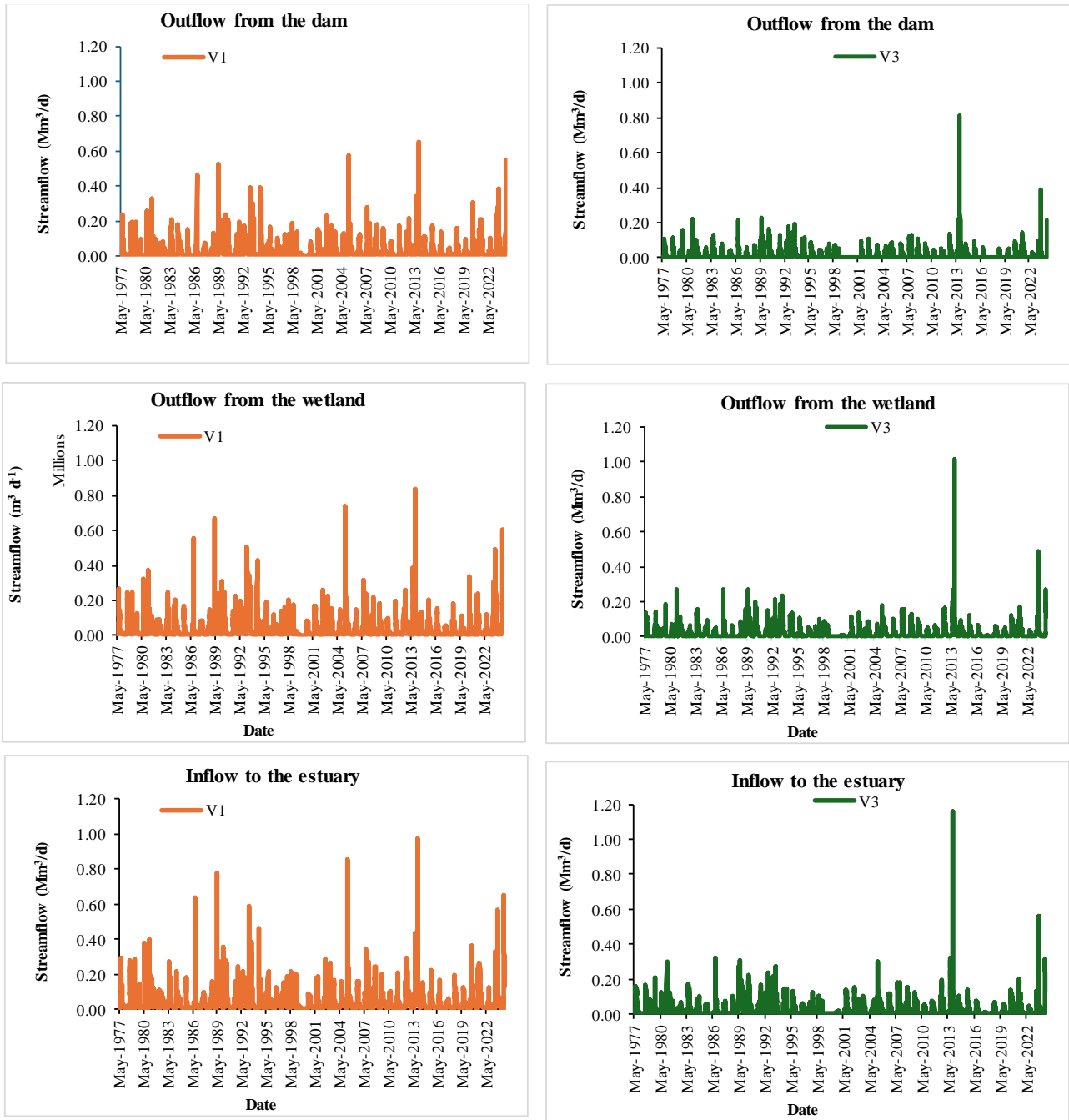


Figure C2: Simulated Scenario V1 compared to V3.

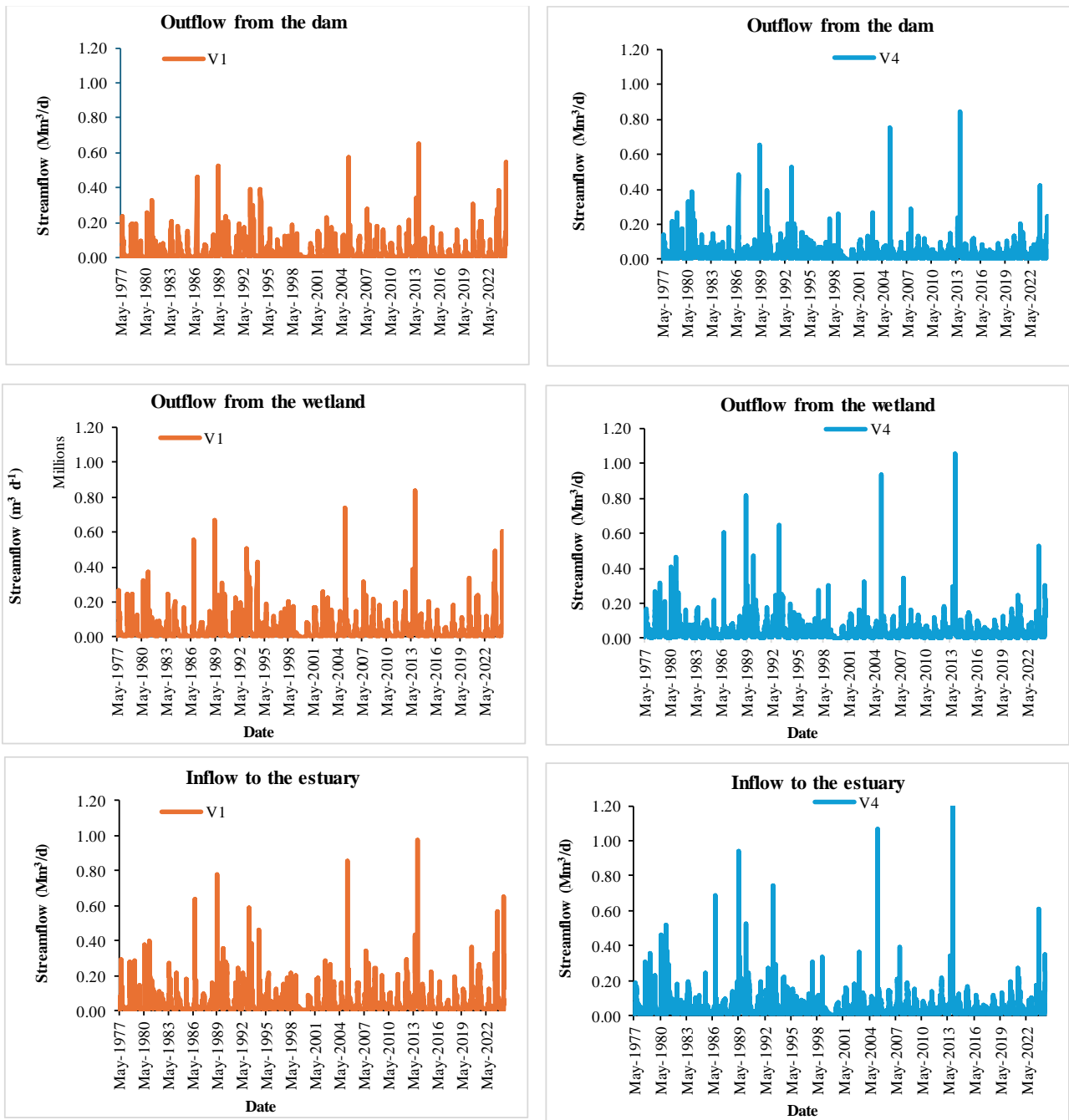


Figure C3: Simulated Scenario V1 compared to V4.

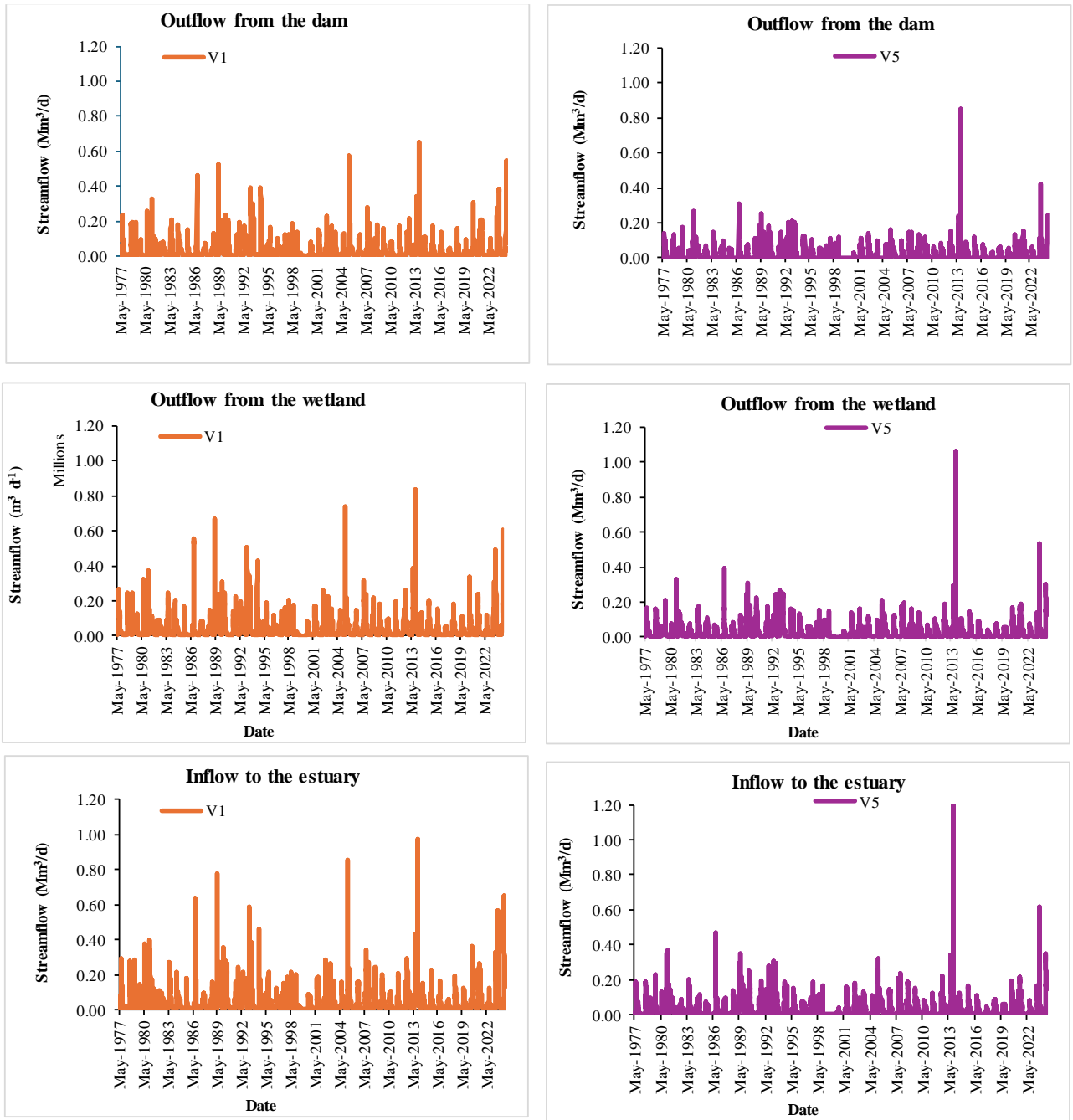


Figure C4: Simulated Scenario V1 compared to V5.

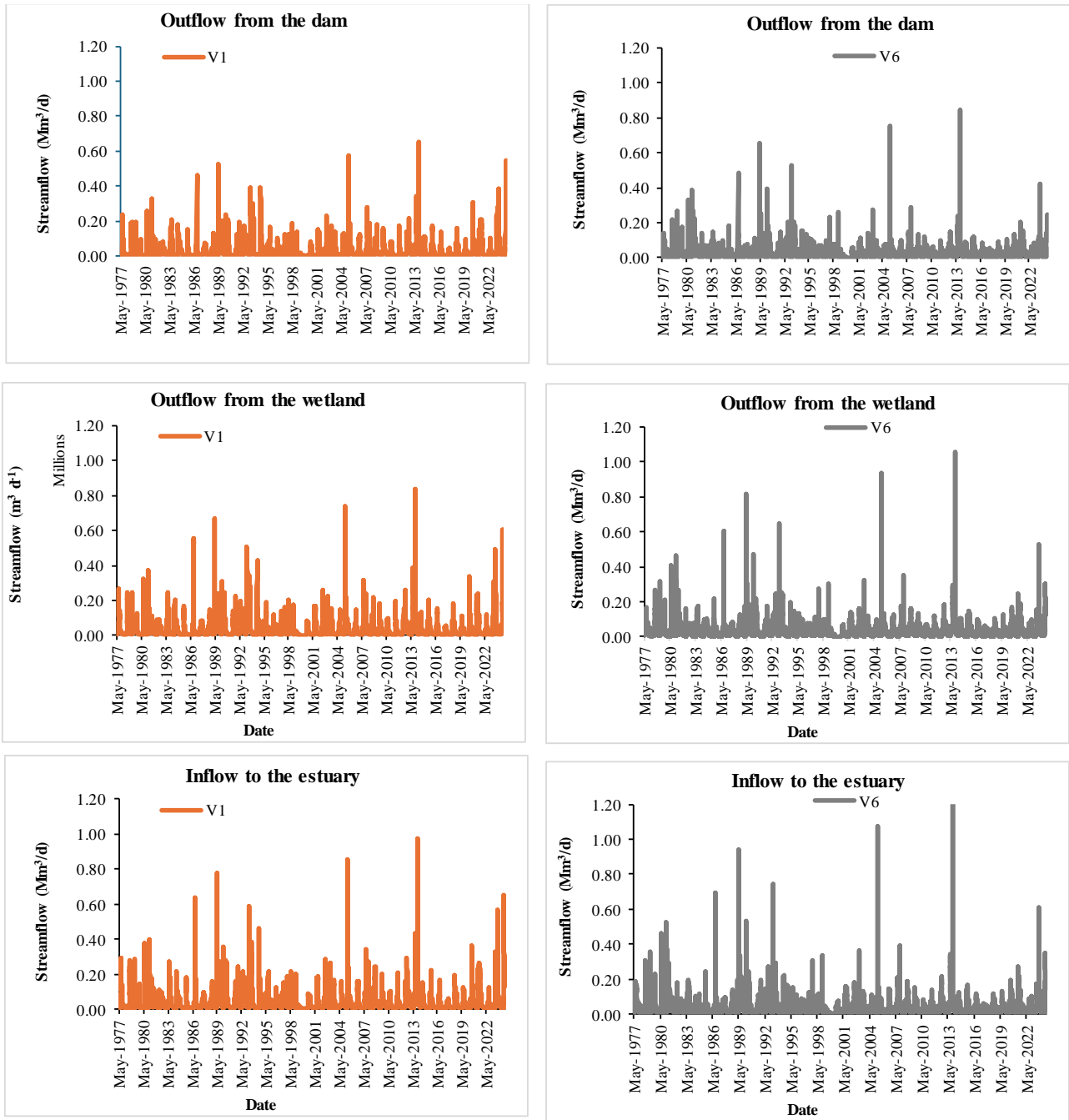


Figure C5: Simulated Scenario V1 compared to V6.

Appendix D: Observed and Simulated Flow Regimes

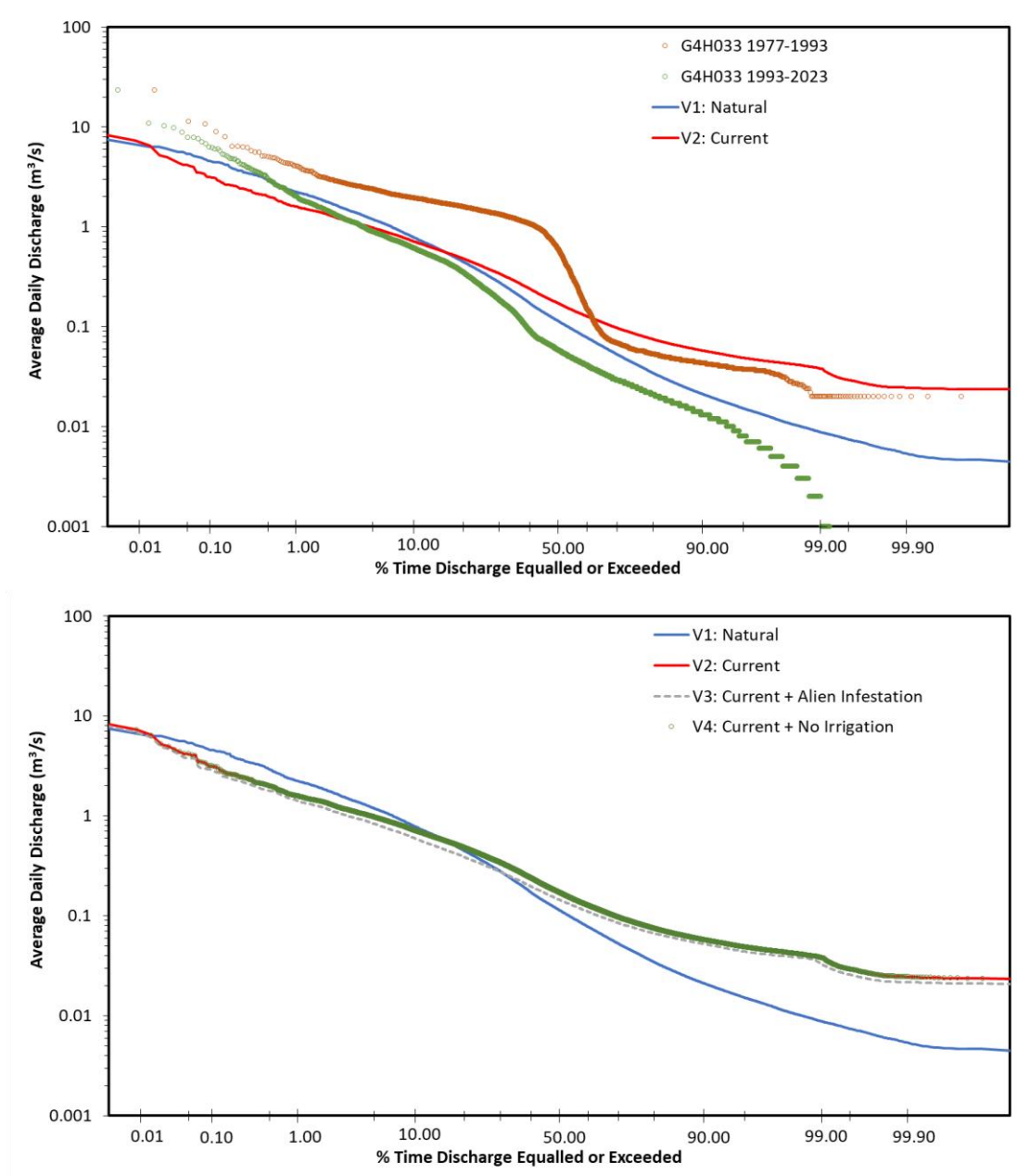


Figure D1: Flow regime at the DE BOS DAM INLET for observed flows (weir G4H033 1997-1993 and 1993-2023) and simulated V1-V2 (above) and for simulations V1 – V4 (below).

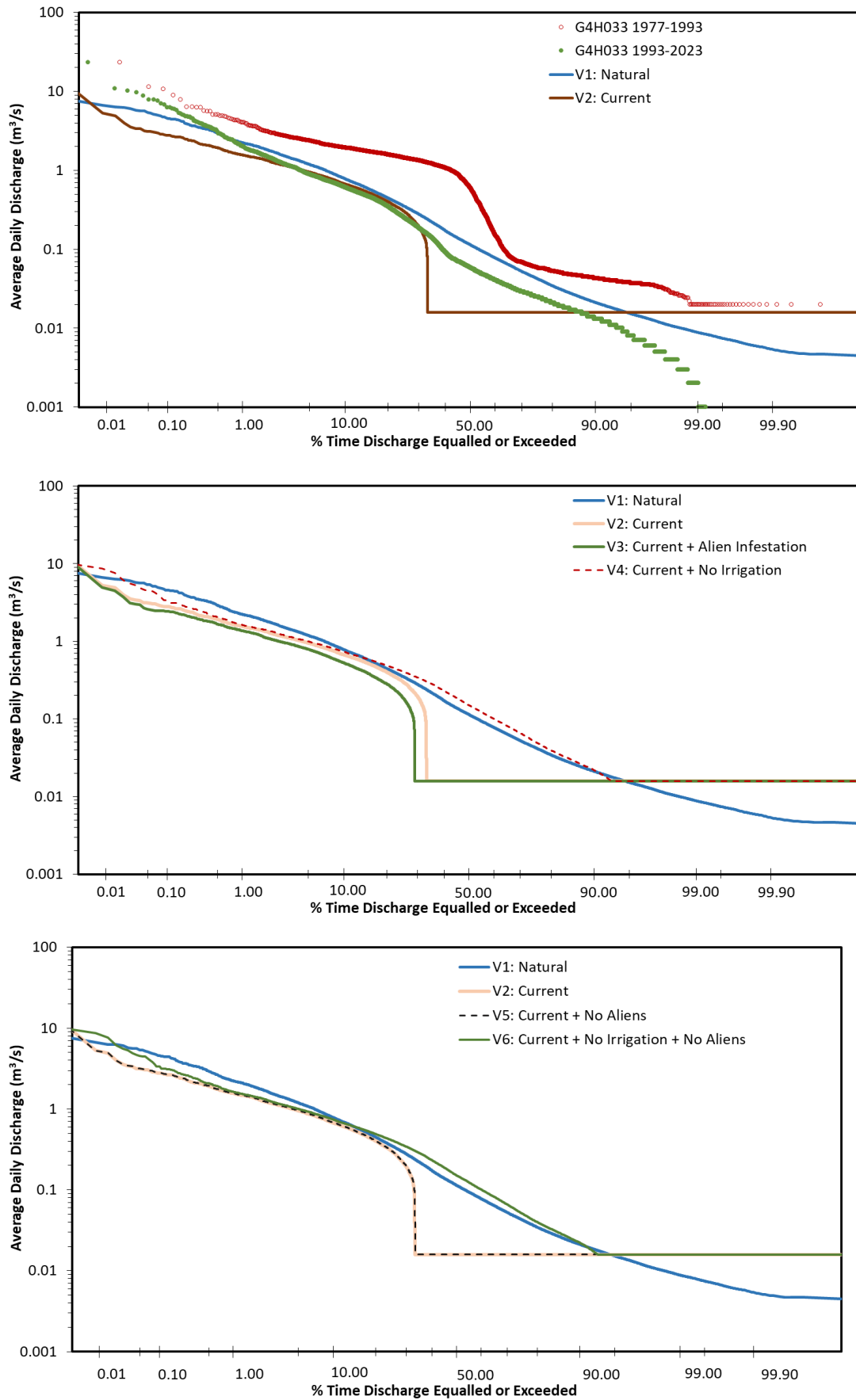


Figure D2: Flow regime at the DE BOS DAM OUTLET for observed flows (G4H033 1997-1993 and 1993-2023) and simulated V1-V2 (above), V1 – V4 (middle) and V1-V2; V5-V6 (below).

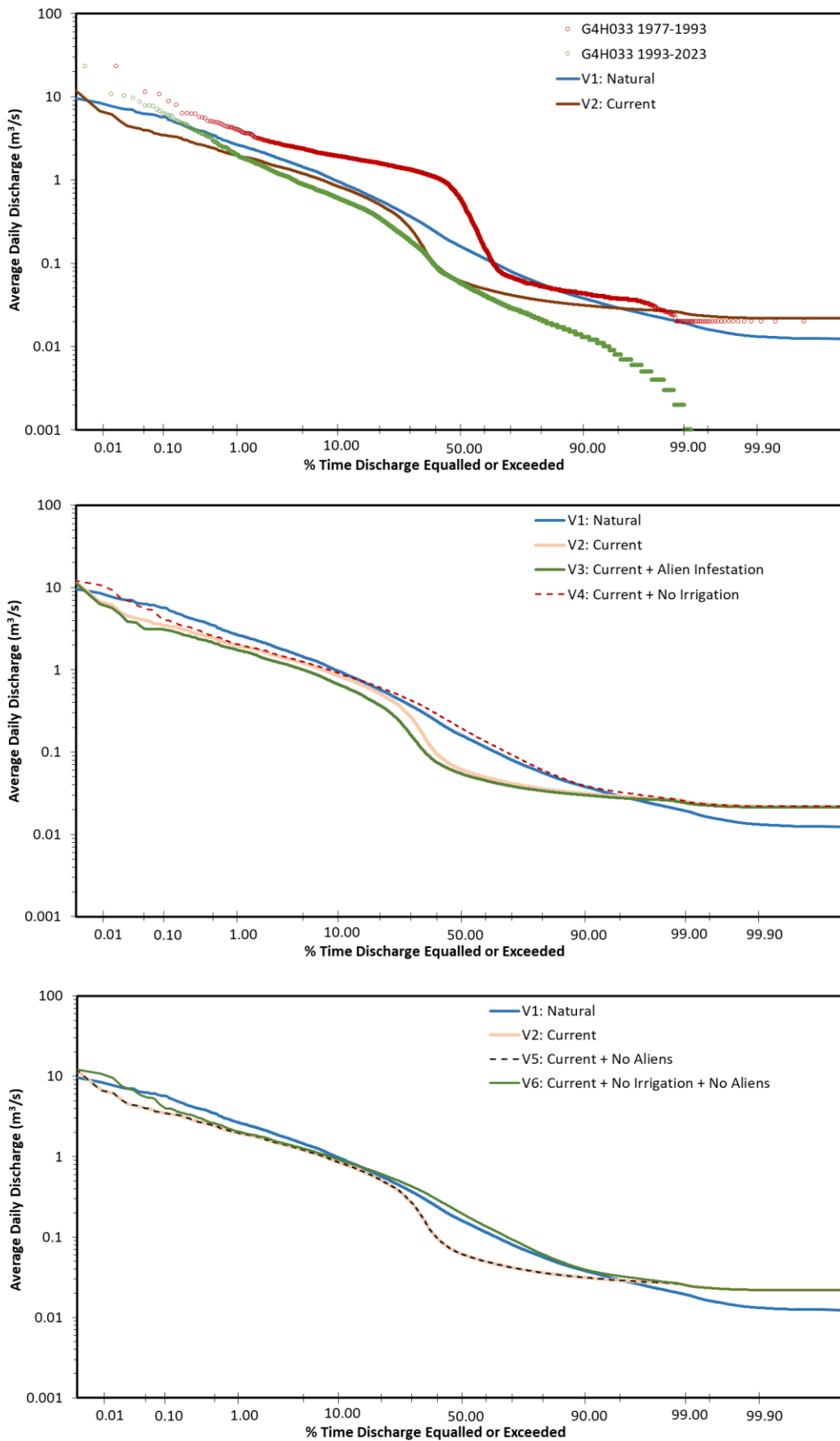


Figure D3: Flow regime at the WETLAND for observed flows (G4H033 1997-1993 and 1993-2023) and simulated V1-V2 (above), V1 – V4 (middle) and V1-V2; V5-V6 (below).

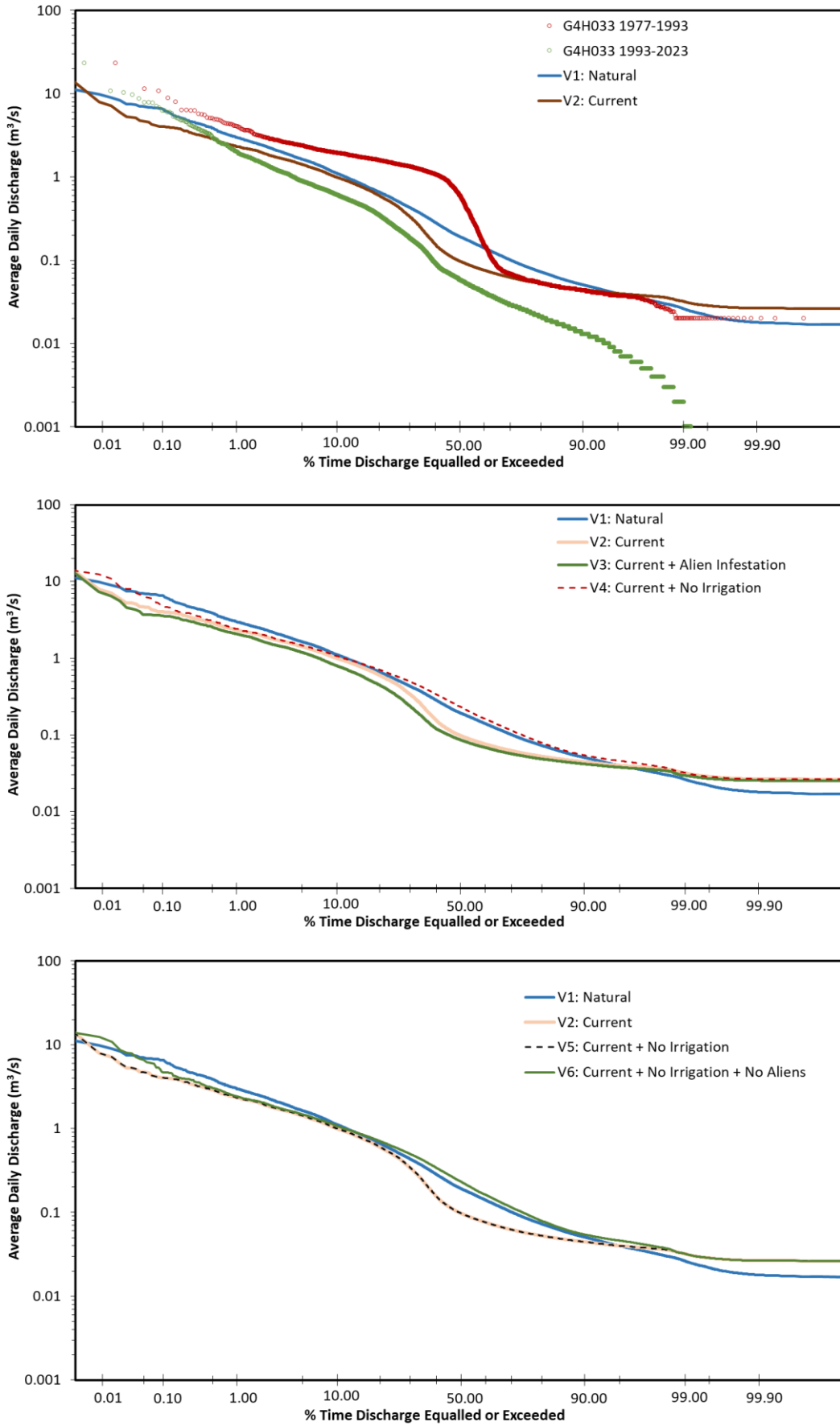


Figure D4: Flow regime at the ESTUARY for observed flows (G4H033 1997-1993 and 1993-2023) and simulated V1-V2 (above), V1 – V4 (middle) and V1-V2; V5-V6 (below).

Appendix E: Extreme Value Distributions

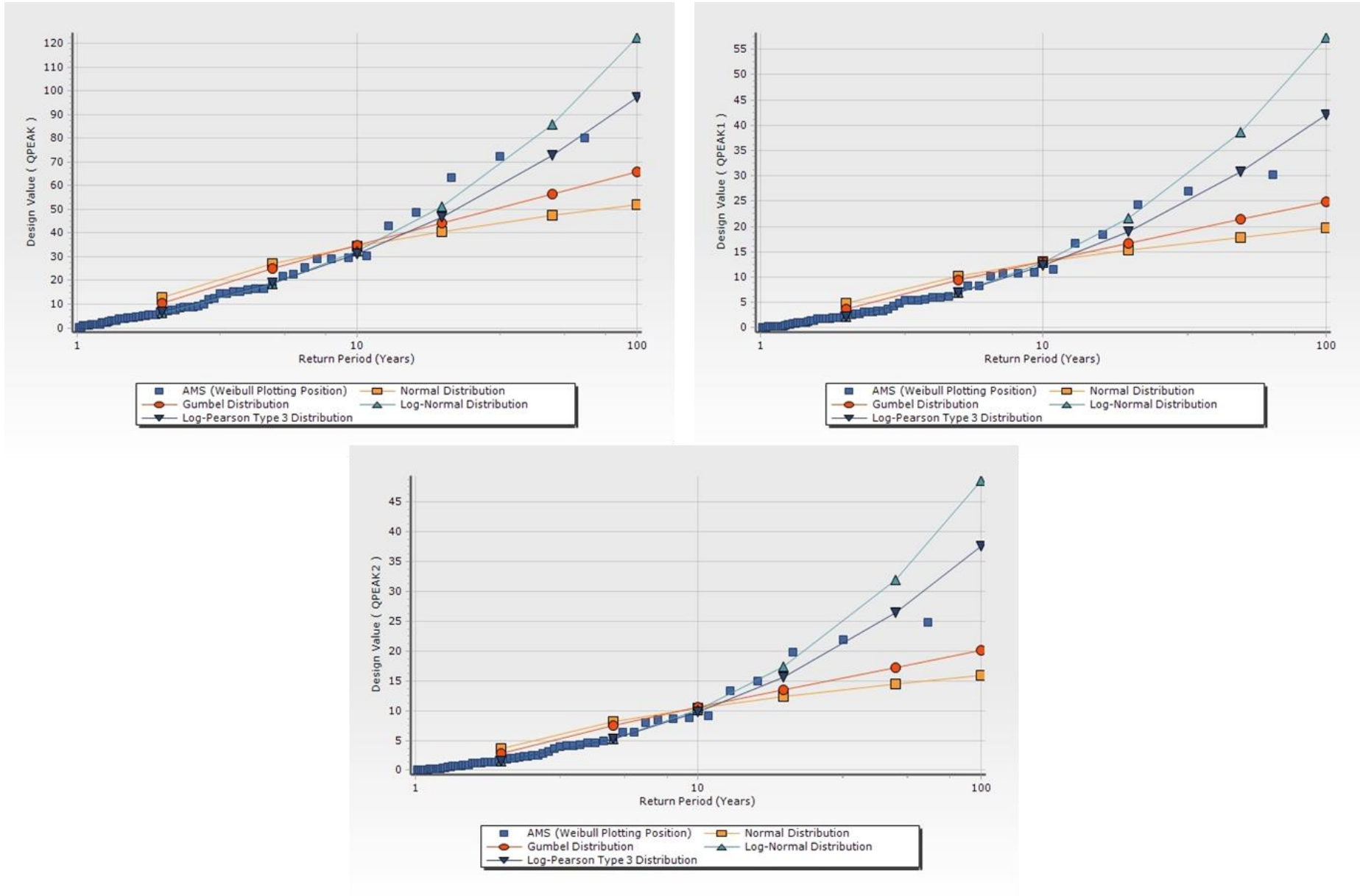


Figure E1: Extreme Value Distribution of QPEAK (m³/s) for SCENARIO V1. (Top L-R): Dam In; Wetland, (Bottom): Estuary.

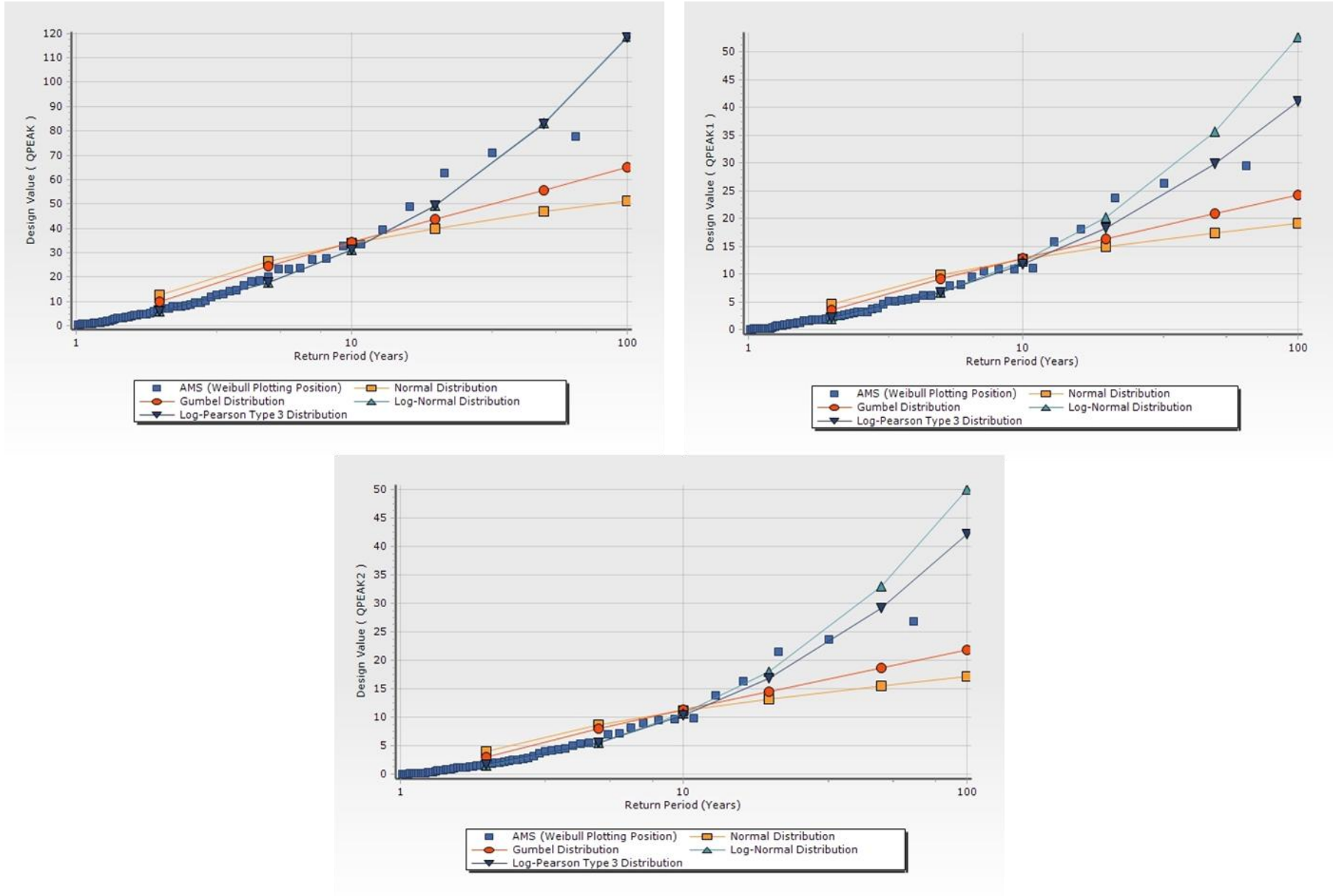


Figure E2: Extreme Value Distribution of QPEAK (m³/s) for SCENARIO V2. (Top L-R): Dam In; Wetland, (Bottom): Estuary.

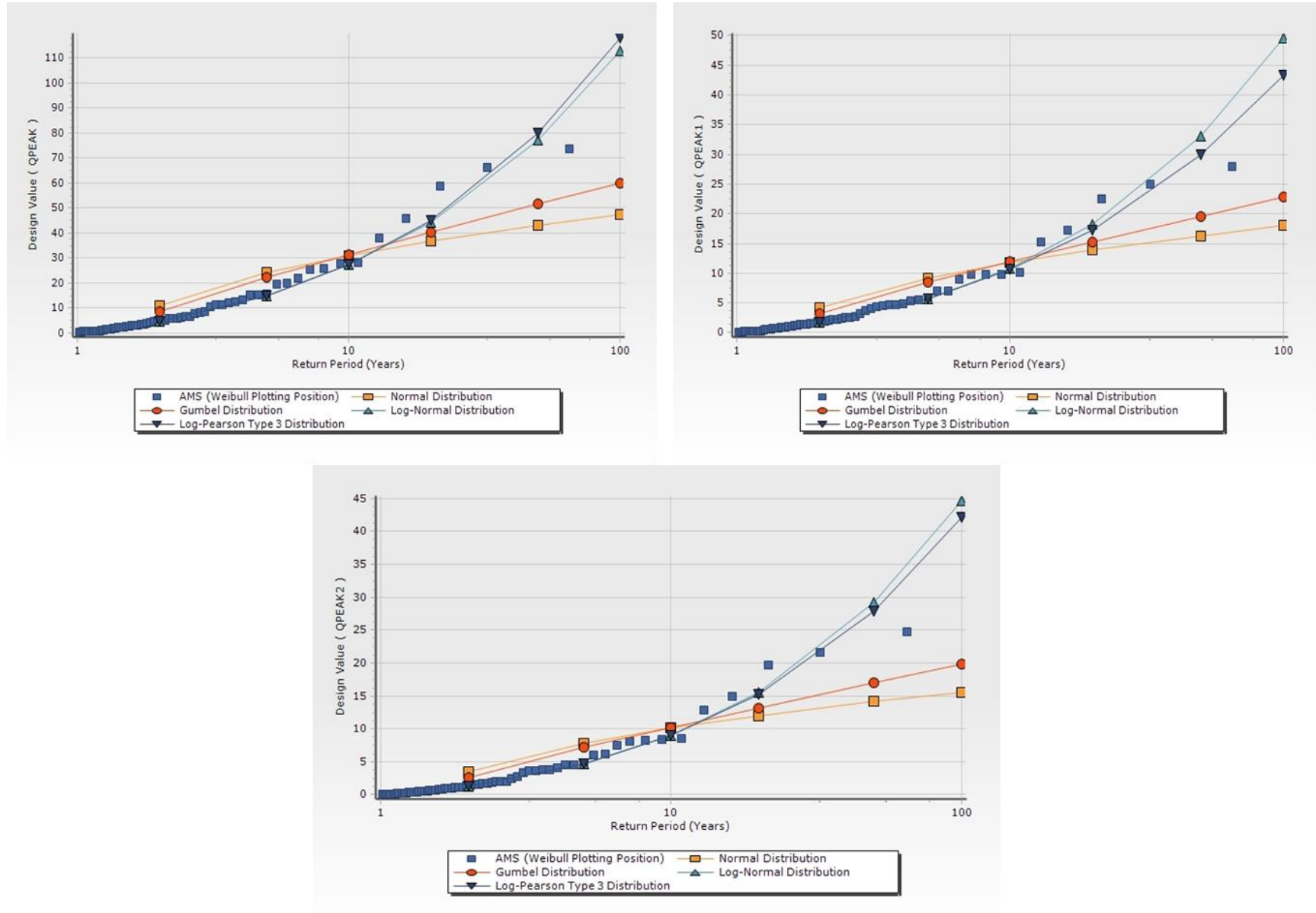


Figure E3: Extreme Value Distribution of QPEAK (m³/s) for SCENARIO V3. (Top L-R): Dam In; Wetland, (Bottom): Estuary.

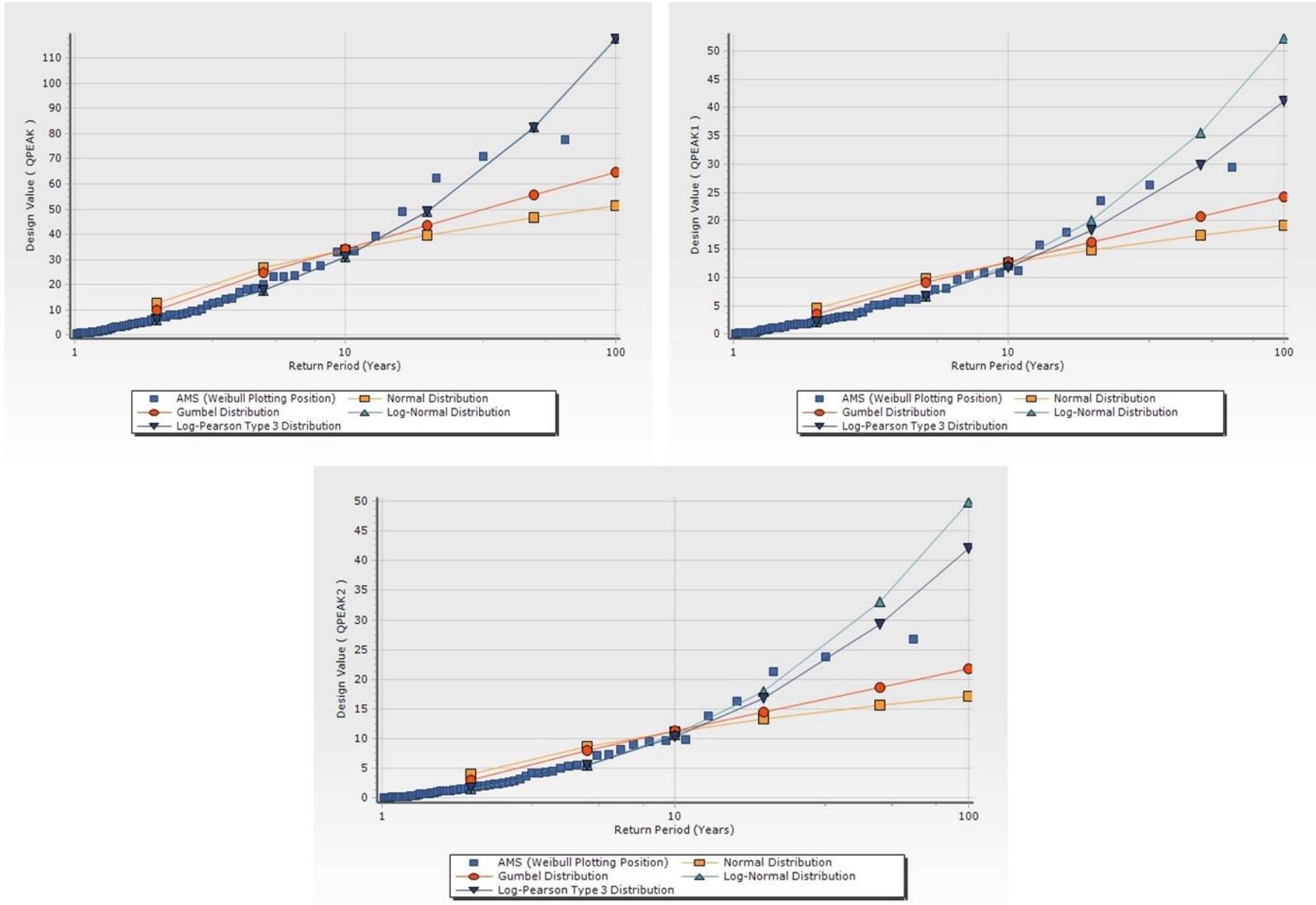


Figure E4: Extreme Value Distribution of QPEAK (m³/s) for SCENARIO V4. (Top L-R): Dam In; Wetland, (Bottom): Estuary.

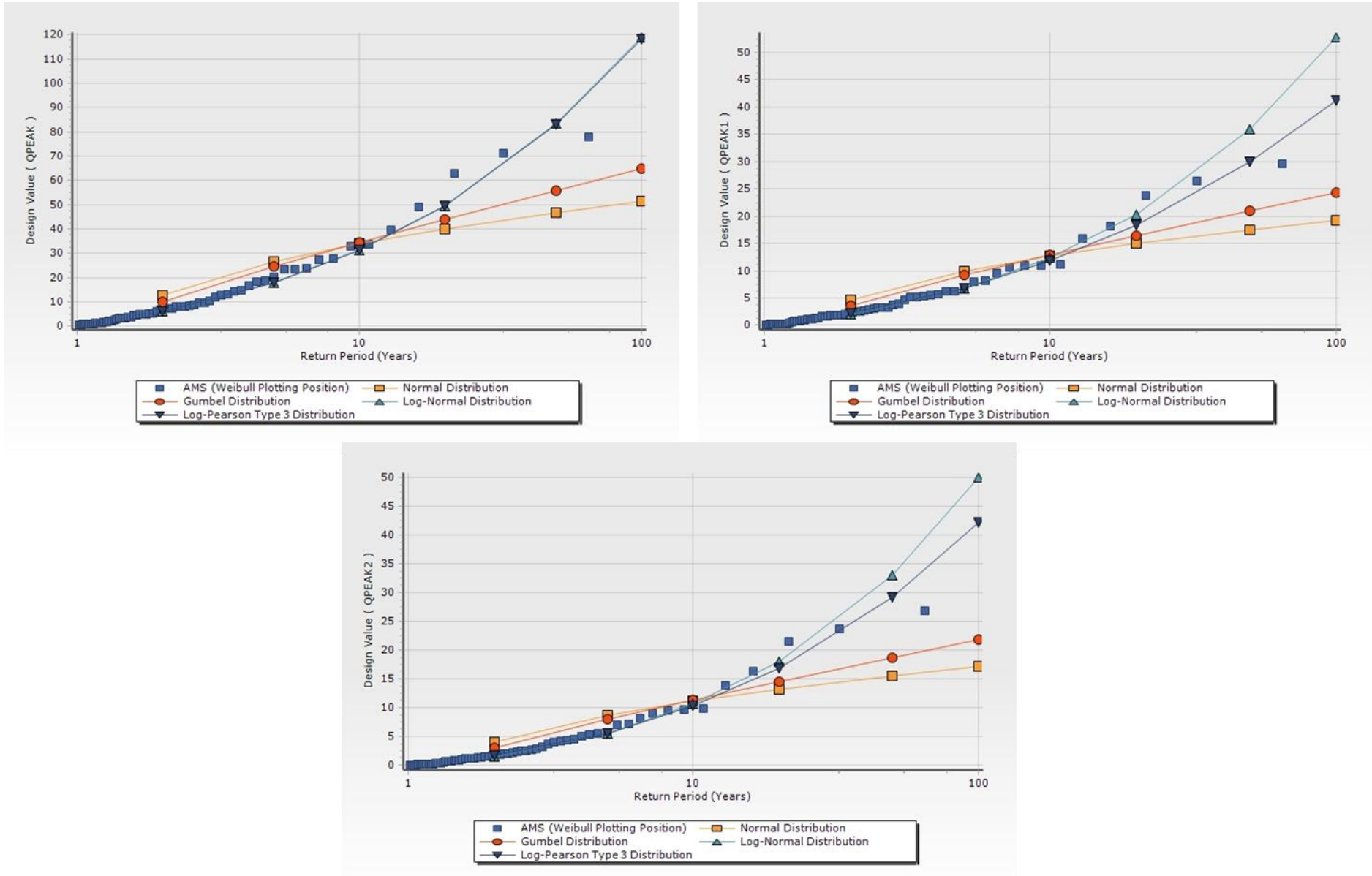


Figure E5: Extreme Value Distribution of QPEAK (m³/s) for SCENARIO V5. (Top L-R): Dam In; Wetland, (Bottom): Estuary.

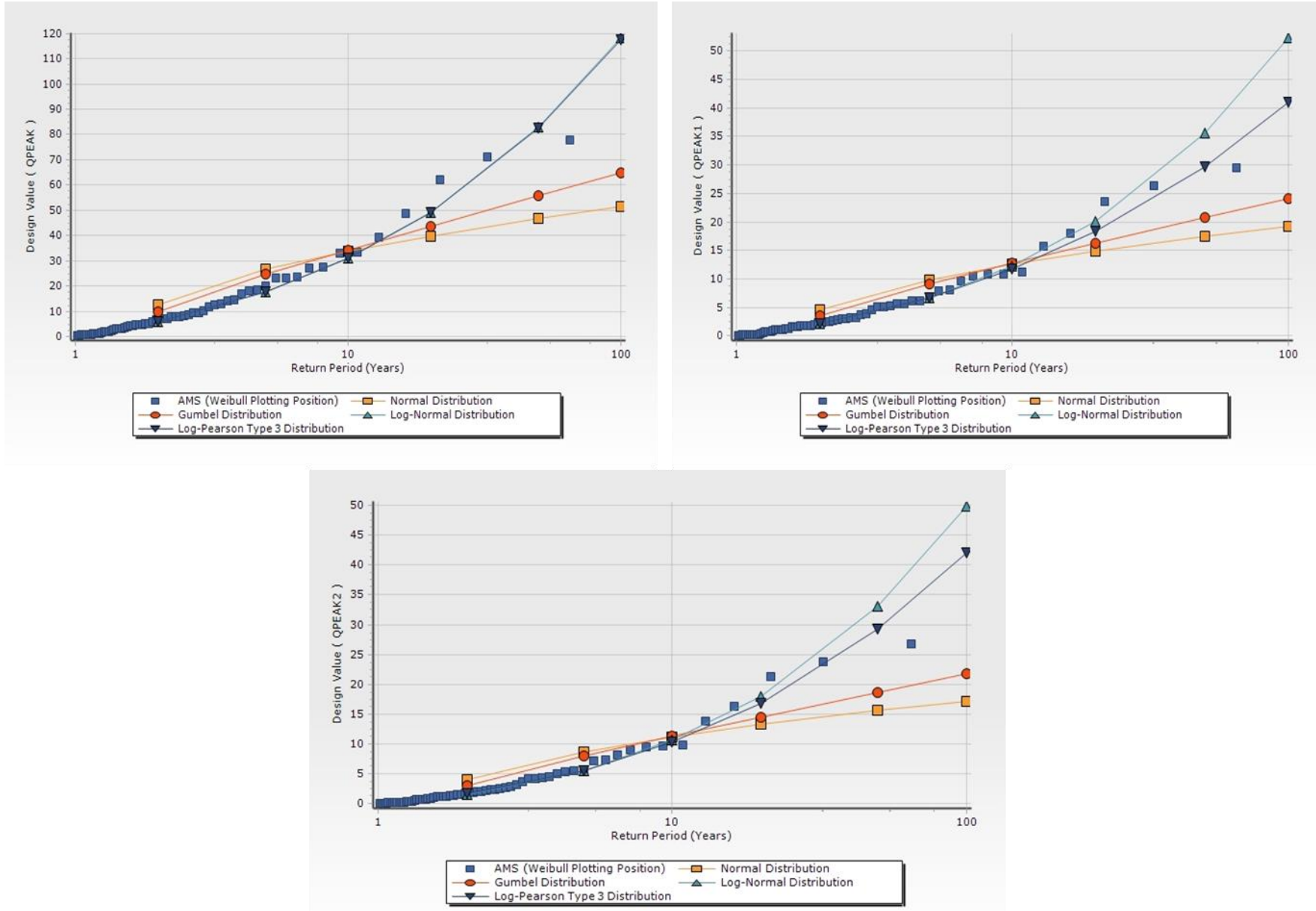


Figure E6: Extreme Value Distribution of QPEAK (m³/s) for SCENARIO V6. (Top L-R): Dam In; Wetland, (Bottom): Estuary.

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