Real-time application of the PROBFLO framework risk approach as a part of the digital twin towards the implementation of environmental flows in the Limpopo Basin, southern Africa

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INFORMATION

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ABSTRACT

The natural world consists of various complex physical, biological and social systems that are connected and interact with each other. New technological developments are improving the ability of the managers of our natural resources, to understand and contribute to the way we are developing using and sometime abusing our resources. Through the Digital Twin for management of water resources in the Limpopo River Basin we have an opportunity to integrate available sustainable environmental flows and water resource management technology into an integrated system, that will allow stakeholders of the Limpopo River and surrounding regions to understand, monitor and manage these resources for current and future generations.

Environmental flow (e-flow) determination tools have been designed to provide stakeholders of rivers with the flow requirements needed to protect the river ecosystems. While useful as a development control these e-flows usually only represent a small part of the sustainable development problem that resource stakeholders face. Managers have the needs of people to consider and other stressors to manage including water pollution, habitat loss, barriers, alien invasive species and climate uncertainty. Modern PROBFLO e-flow determination applications in the Limpopo River Basin are holistic and considers flow and non-flow variables of change. The PROBFLO approach also considers the risk of natural, present, e-flow and future drought flow scenarios in the context of non-flow stressors to supporting, provisioning, regulatory and cultural services. This once off PROBFLO assessment has been useful but is not adaptable in its current form and while valuable the probability risk model was used once and is not available to managers of the water resources and people of the Limpopo Basin who consider a range of alternative development and protection scenarios.

The real-time application of the PROBFLO framework risk approach for the Limpopo River through the Limpopo River Digital Twin solves this problem through the establishment of and testing on an internet based PROBFLO EFA application tool. The tool combines a range of software and the PROBFLO e-flow models into a single user-friendly tool that stakeholders can use to consider any past or present water use scenario for the Limpopo River. The PROBFLO EFA application tool was developed for the Balule River site on the Limpopo River and is available for roll out to the rest of the basin. The tool allows users to change the flow scenario and condition/state of any non-flow stressor including water pollution, habitat loss, barriers, alien invasive species etc. and evaluate the risk of this new scenario to the supporting, provisioning, regulatory and cultural services established in the PROBFLO assessment. Users can use the risk results to consider the risk of a range of unique scenarios including new development options, they can consider trade-off considerations between social and

ecological endpoints and between locations throughout the basin. The PROBFLO EFA application tool is a useful component of the new Digital Twin for the Limpopo River basin and will contribute to sustainable water resource management in the region.

INTRODUCTION

The world needs to attain a sustainable balance between the use and protection of the resources that we depend on for our survival (Nhamo et al., 2019; Cetrulo et al., 2020; Kuehne et al., 2023). People are totally dependent on the water resources that we derive our water from for domestic use and other ecosystem services (Cetrulo et al., 2020, O'Brien et al., 2020). While there are many pristine ecosystems in the world that have a high potential for development and the provision of services, the Anthropocene has affected the majority of the world's rivers (Arthington et al., 2023; Kuehne et al., 2023). Most of the rivers in the world today are overutilized and cannot provide people with the ecosystem services that they used to provide (Horne et al., 2018). And many of the developed rivers throughout the world are being used in an unsustainable way, while their condition is continuously deteriorating and the services and ecosystems that they have are deteriorating (Kuehne et al., 2023; Thieme et al., 2023). In many developed and developing areas of the world, including southern Africa, water resources have been highly developed and users have higher demands for water resources than available from the resources we are using (O'Brien et al., 2020; Wade et al., 2021). The excessive use and need to continually develop resources for the increasing demand for water resources results in multiple stressors that urgently need to be managed before we run out of resources in these regions (O'Brien et al., 2020; Wade et al., 2021). Implementation of environmental flows (e-flows) has become a global sustainable water resource management initiative (Horne et al., 2018; Arthington et al., 2023). Arthington et al. (2018) established e-flows as the volume and quality of water required to remain in a river to sustain the ecosystem and hence all those who benefit from a functional ecosystem. The e-flow approach is valuable not only to determine the sustainability requirements of water resources but to contribute to the establishment of sustainability management plans, their implementation and monitoring towards attaining a sustainable balance between the use and protection of water resources (Arthington et al., 2023). Many e-flow determination methods and associated frameworks designed to contribute to the implementation of e-flows exist and have been implemented globally (Horne et al., 2018; Arthington et al., 2023). The e-flow requirements are generally easy to interpret and use to meet targets or for flow release management or e-flow implementation (Arthington et al., 2023), but few e-flow determination methods and frameworks are adaptable to learn from existing information and improve e-flow predictions, and to allow scrutiny by stakeholders, or allow scenario assessment as required by water resource management towards sustainable implementation (O'Brien et al., 2018).

A digital twin initiative being implemented by IWMI in the Limpopo River Basin (LRB), endeavours to make e-flow frameworks available for use and to contribute to e-flow implementation (Garcia Andarcia et al., 2024), while maintaining the accuracy and robustness of existing e-flow assessments. As part of this, an internet of things (IOT) application for the real-time use/implementation of the PROBFLO e-flow risk framework for the LRB has been developed. PROBFLO is an e-flow determination tool and framework with capabilities to model the holistic requirements of ecosystems that inform holistic e-flow determination and present the socio-ecological consequences or risk of altered flows on ecosystem services (Horne et al., 2017; O'Brien et al., 2018). Following the application of PROBFLO to determine e-flows and evaluate the socio-ecological consequences of altered flow scenarios (past, present, e-flows and a future climate change scenarios)(O'Brien et al., 2022), the objective of this study is to support the implementation of e-flows through the digital twin approach for e-flow implementation towards sustainability. While monitoring e-flow volumes from a hydrological and water quality perspective is a relatively simple matter, monitoring the effectiveness of the prescribed e-flows and the socio-ecological response of e-flow provision requires evidence of a sustained ecosystem and associated condition of human communities following e-flow implementation. In this study we considered the application of innovative digital tools and the collection of and use of real-time ecosystem monitoring data for e-flow management in the Limpopo Basin.

The aim of this research was to facilitate the continued development of the PROBFLO e-flow framework into an adaptive framework that is accessible to stakeholders to evaluate real-time and future scenarios from existing PROBFLO risk models. In the process, to introduce learning capabilities to the PROBFLO framework models to learn and update the understanding/representation of the socio-ecological system of interest and the risk of altered flow projections. This results in an improved ability of the PROBFLO Framework to automatically predict future socio-ecological consequence of altered flows, and addition of other stressors as applied by stakeholders. Presently this can only be carried out by experienced e-flow scientists in a reactive manner, while real e-flow management needs to be pro-active. To achieve this the adaptability of e-flow framework implementation is required. In this paper we describe the PROBFLO software application development and testing as a part of the digital twin programme, "Harnessing Digital Technologies for Timely Decision-Making Across Food, Water and Land Systems" for the Limpopo River Basin (Garcia Andarcia et al., 2024).

METHODOLOGY

In this study we describe the development of and testing of the PROBFLO e-flow framework (EFR) tool for the Balule River site on the Olifants River, following earlier assessment as part of the Limpopo e-flow study (O'Brien et al., 2022). The approach includes description of the development of (1) the RM-BN risk model and (2) its application and availability as a framework for stakeholders to use. Then (3) we describe the use/development of the Norsys Netica® Application Programming Interface (API) with additional Microsoft Excel® integration and the development of (4) a front-end and (5) back-end for stakeholders use online. Together this represents the first development and demonstration of a user-friendly tool empowering stakeholders with the ability to test and use technical, holistic e-flow frameworks. The availability of the tool and ability to test any scenario would allow users to test alternative flow regimes or any other stressor condition to determine how this would impact on the sustainability of the ecosystem. It would also allow manipulation of the risk - profiles to various beneficiaries of the river ecosystem. Managers would have the ability to consider trade-offs between social and ecological endpoints and risk between different locations throughout the study area.

The PROBFLO Framework software application tool has being developed for the operationalisation of the Limpopo River PROBFLO e-flow framework for use by stakeholders of the LRB as tested in the Olifants River tributary. This approach incorporates the PROBFLO e-flow application, model and framework and the application development resulting in the PROBFLO EFA Tool.

PROBFLO is a holistic e-flow assessment method that includes both the relative-risk model and Bayesian Network – Relative Risk Model (BN-RRM) into a probabilistic modelling tool that explicitly addresses uncertainty (O'Brien et al., 2018). PROBFLO evaluates the socio-ecological consequences of various water resource scenarios and generates e-flow requirements on a regional spatial scale. It follows the ecological risk assessment exposure and effects approach, with multiple stressors, habitats and ranked ecological impact relationships displayed in graphical Bayesian Network (BN) models that use conditional probability distributions to represent the relationship between the variables (O'Brien et al, 2018). The PROBFLO approach is based on ten procedural RRM steps (O'Brien et al., 2018). Broadly this entails the selection of socio-ecological endpoints to represent the established vision for the study area. For the Limpopo study, these endpoints were related to the ecosystem services provided by water resources, namely: supporting services, provisioning services, regulatory services and cultural services. A detailed review is undertaken of the available regional water resource management policies, information on ecosystems, their features, hydrology, processes and drivers and ecosystem services and the vulnerable human communities that depend on these services. With this information a conceptual model representing the multiple stressors (eg flow, water quality, habitat, climate change and alien invasive species) and their synergistic effects on the wellbeing of the rivers, ecosystems and ecosystem services is established as the foundation for a risk assessment framework for the basin. Important stressor-ecosystem and stressor-ecosystem service relationships are identified and used to establish the risk assessment framework and improve the understanding of these relationships through fieldwork. This information is used to construct RRM-BN probability models for the risk framework to determine e-flows and the risk that e-flows and other hydrological scenarios will have on the social and ecological endpoints in the Limpopo Basin. This approach has been implemented in various areas in Africa including the Senqu River for the Lesotho Highlands project (O'Brien et al., 2018), the Mara River in Kenya (O'Brien et al., 2018), the Inner Niger Delta floodplains in Mali (O'Brien et al., 2020), the Limpopo Basin (O'Brien et al., in preparation and O'Brien et al., 2022; Wade et al., in preparation) and the Incomati Basin (Wade et al., in preparation).

Through the CGIAR Initiative "Harnessing Digital Technologies for Timely Decision-Making Across Food, Water and Land Systems", the need to establish a Limpopo Basin E-flows Framework stakeholder-friendly application tool that allows stakeholders to test any scenario and to contribute to the improvement of the Limpopo E-flows Framework predictions resulted in the PROBFLO EFA Tool (visit probflo.riversoflife.co.za). The PROBFLO EFA application is a web application incorporating multiple APIs into a single user-friendly but comprehensive platform. This tool combines data analysis with the PROBFLO Bayesian network modelling (The Nors Netica Bayesian Network Networks foundation to this component https://www.norsys.com/netica.html) into the online application that can be accessed by any stakeholder. The features of the Application Tool are described below, while the documentation and specifications are provided in the Annexure.

PROBFLO EFA APPLICATION

A PROBFLO framework was developed for the whole of the LRB to provide the risk of river flow implementation outcomes for 25 specific river reaches, depending on the river specific information inputted into the framework (O'Brien et al., 2022). A separate Bayesian Network was developed for each river reach and site as each would have unique flow-ecosystem relationships that need to be taken into consideration. These flow-ecosystem relationships are presented as rule or conditional probability tables (Figure 1a) or stacked area graphs (Figure 1b). For this case study, the PROBFLO EFA Tool was developed for the Balule site on the Olifants River based on the Netica Bayesian network model provided in Figure 2.

A

FISH_ECO_VD				
(m^3/s)	Zero	Low	Med	High
0	0	0	0	100
0.9	0	15	80	5
1.8	4	25	70	1
2.7	10	40	50	0
3.6	20	65	15	0
4.6	85	15	0	0
11.1	90	10	0	0
20.9	95	5	0	0
34.2	95	5	0	0
51	95	5	0	0
71.5	95	5	0	0
95.8	95	5	0	0
124	95	5	0	0
156.3	95	5	0	0
192.6	95	5	0	0
233.1	95	5	0	0
277.9	95	5	0	0
327	95	5	0	0
380.4	95	5	0	0
438.2	95	5	0	0
500.6	95	5	0	0
567.5	95	5	0	0
638.9	95	5	0	0
715	95	5	0	0
795.8	95	5	0	0
881.3	95	5	0	0
971.6	95	5	0	0
1066.7	95	5	0	0
1166.6	95	5	0	0

B

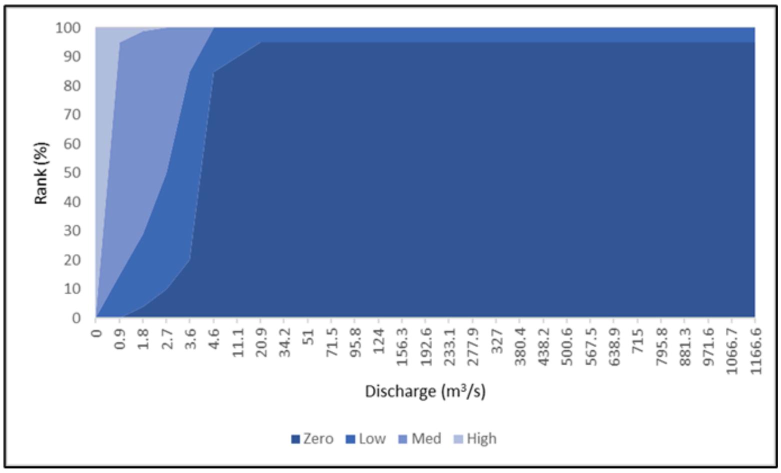


Figure 1: Example of a flow-ecosystem relationship established for the Balule site to represent the suitability of velocity-depth habitat characteristics for indicator fishes associated with discharge. A) represents relationships which are in B) graphically presented.

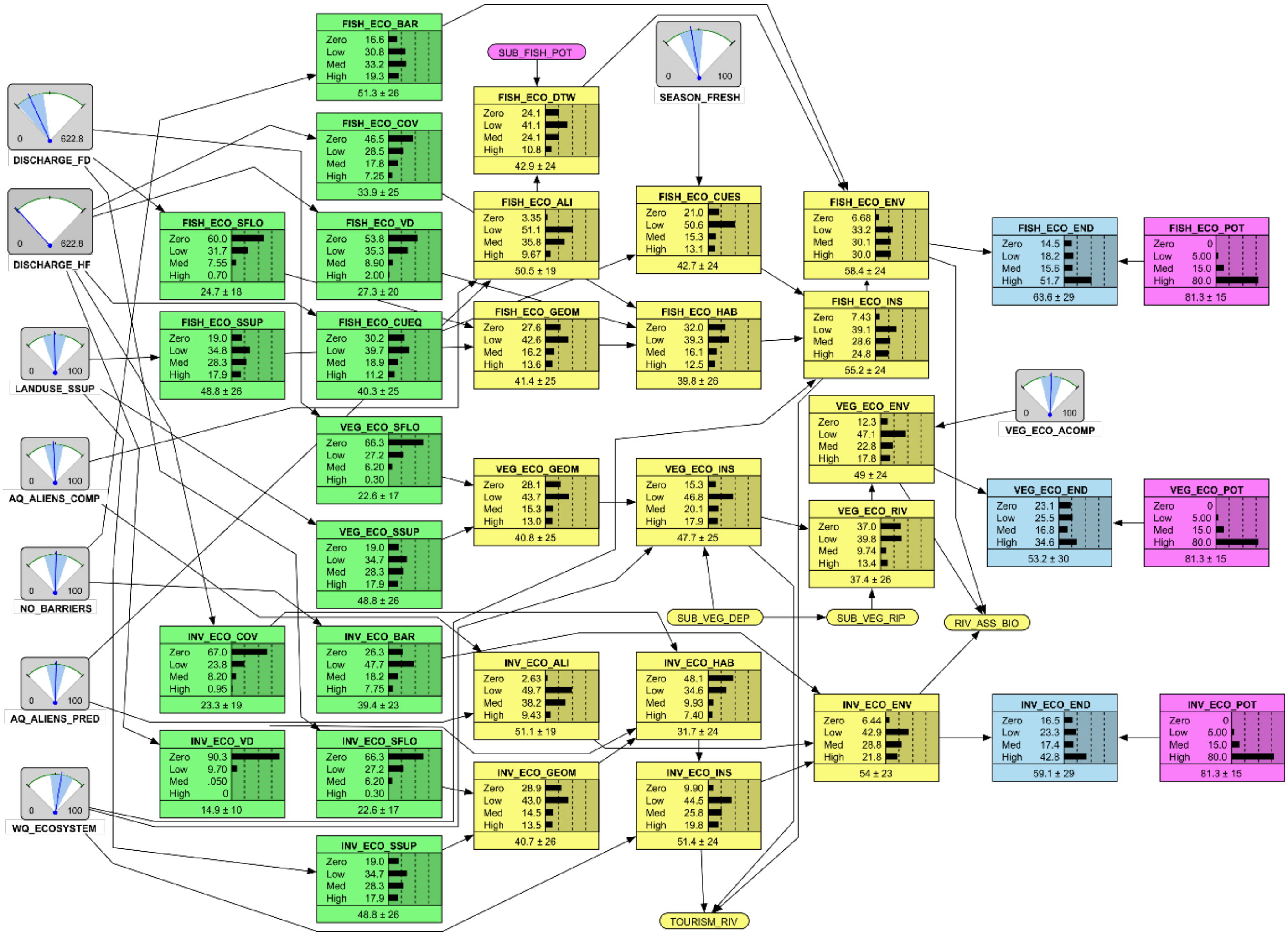


Figure 2: Bayesian Network risk model developed and used in the e-flow determination process for the Limpopo River e-flow study (O'Brien et al., 2022).

In 2018 the e-flows for all the major rivers in the Olifants catchment were gazetted the by South African Department of Water Affairs (DWS, 2018) and thus cannot be amended without due process, so new e-flows for the Balule site were not established using PROBFLO but instead the gazetted e-flows were tested to determine the risk they posed to the socio-ecological endpoints. The total natural mean annual runoff (MAR) for the Balule site is 1918 106m3 and the e-flow provided in the gazette (DWS, 2018) is 21.06% of the total, including 10.01% of the MAR allocated for droughts or 17.72% of the flow for base, dry and wet periods and an additional 3.34% of the MAR for annual freshets and floods. This hydrology is represented as a flow duration Table 1c with monthly percentile distributions of which the nodes of the Bayesian Network query directly. The tool considered hydrological scenarios in flow-duration table formats and typically is provided with foundational scenarios including "natural" (Table 1a), "present" (Table 1b), "e-flow" (Table 1c) and "future" drought (Table 1d) hydrology scenarios, presented as flow duration tables that are available in the framework and can be used to direct future management of river flows.

The PROBFLO EFA Tool enables users to automatically generate and test a flow scenario and provide the risk outcomes for endpoints without the user having to develop BNs and or interact with Netica, as it applies existing, tested BN models.

This approach allows users to test any scenario by modifying the environmental driver options of existing PROBFLO Netica BN models. To achieve this the Netica model requires information from the user that can be uploaded into the input nodes of the Netica model as a case file but without the need for the user to engage with Netica software, the engagement is done automatically by the PROBFLO EFA Tool. This includes flow information and non-flow related characteristics of the socio-ecological system as well as the hydrology for the scenario to be considered. This can be undertaken in three steps using the PROBFLO Application Tool including:

- represent the non-flow ecosystem variable condition or state of "system drivers" using front-end questionnaire,
- generate and upload a hydrology scenario for assessment, upload the hydrology into the Bayesian Network, and
- implement the risk assessment including the hydrology scenario and system driver states to determine the risk of the scenario to the socio-ecological endpoints determined in the PROBFLO assessment.

The PROBFLO EFA Tool allows users to generate and test flow scenarios that are provided in standard flow duration formats (Table 1). Sites that have been considered in PROBFLO assessments are available to establish PROBFLO EFA Tools and test new flow and multiple stressor scenarios. The user must also populate the state of and or condition of

Table 1: Flow duration table for the A) natural, B) present, C) e-flow and D) future drought hydrology scenarios for the Balule site.

A

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.1	164.0	280.7	449.8	563.7	1166.5	683.0	388.6	115.6	56.0	42.5	33.1	39.1
1	144.1	254.3	302.1	492.8	1142.4	608.8	247.6	94.5	55.2	38.4	32.6	36.7
5	48.3	167.3	220.1	352.9	558.6	353.1	142.1	68.3	42.4	31.3	25.8	25.4
10	39.7	138.2	162.3	299.3	385.1	236.4	112.3	54.8	36.8	29.0	21.2	22.9
15	30.9	118.0	140.3	223.1	299.3	200.5	96.9	47.3	33.0	24.6	19.6	18.0
20	26.1	96.2	127.4	181.2	250.1	174.0	82.2	43.8	29.0	22.9	18.4	17.0
30	21.4	68.5	108.0	121.7	118.2	120.4	62.9	36.5	26.2	19.7	15.7	14.7
40	18.0	52.4	93.8	93.1	88.9	84.8	52.2	31.1	22.1	18.1	14.7	12.7
50	16.1	44.5	77.3	76.1	76.7	56.4	44.1	27.2	20.5	15.5	13.1	12.0
60	13.0	35.6	57.7	66.1	61.4	49.5	38.2	24.8	18.8	14.6	12.1	10.8
70	10.8	28.4	46.7	53.3	49.8	39.4	32.9	21.3	16.1	14.0	11.5	10.0
80	10.2	21.7	33.2	44.7	44.4	34.5	24.5	17.8	14.6	12.1	10.9	9.0
85	9.9	18.6	30.9	39.9	40.1	31.9	22.8	17.2	13.7	11.3	9.5	8.4
90	8.6	15.1	26.5	33.8	36.7	27.8	21.7	15.9	12.7	10.5	9.0	7.6
95	7.7	12.0	21.6	29.3	30.8	24.5	19.7	14.8	11.9	9.8	8.4	7.2
99	6.9	9.1	14.3	24.1	25.6	18.0	14.6	10.2	9.0	7.7	7.3	6.7
99.9	6.5	7.2	13.9	23.9	22.1	14.5	12.0	9.4	8.1	6.5	7.3	6.7

B

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.1	113.0	140.3	400.9	496.8	987.5	641.9	357.3	72.4	27.9	14.3	10.3	36.1
1	40.1	130.2	198.5	464.1	976.1	566.2	209.0	54.7	25.4	13.2	9.2	17.7
5	10.1	76.2	127.6	225.0	480.1	265.8	109.9	36.3	16.9	10.4	5.7	5.6
10	7.7	48.6	68.3	140.0	297.8	173.4	61.1	29.0	13.4	7.5	4.4	4.0
15	5.2	37.4	56.2	109.8	240.7	134.2	55.8	22.8	12.2	6.6	3.8	3.5
20	4.7	22.0	43.0	90.8	188.8	101.8	47.4	21.4	11.3	6.2	3.0	2.9
30	3.6	15.2	38.4	51.7	70.8	66.0	31.7	17.0	9.1	4.4	2.6	1.6
40	2.6	11.5	28.2	34.3	43.2	38.6	25.3	14.6	7.9	3.5	2.0	1.3
50	2.0	7.4	24.2	25.3	27.6	22.1	20.2	12.8	7.0	3.1	1.7	1.1
60	1.2	4.8	15.7	18.4	22.9	20.3	15.8	10.8	6.3	2.8	1.4	0.8
70	0.7	2.8	10.7	14.4	16.1	16.8	14.4	8.9	4.9	2.4	1.2	0.4
80	0.3	1.7	7.0	10.5	11.3	11.9	11.2	7.2	4.0	1.5	0.6	0.2
85	0.2	1.3	5.9	8.7	10.0	10.0	9.9	6.7	3.4	1.2	0.4	0.1
90	0.2	0.6	2.5	5.8	7.8	8.1	8.2	6.1	2.9	1.0	0.2	0.1
95	0.1	0.3	1.7	4.9	4.8	5.5	7.0	5.2	2.1	0.8	0.1	0.1
99	0.1	0.1	0.6	3.1	3.0	2.8	3.3	1.8	1.3	0.3	0.1	0.1
99.9	0.1	0.1	0.4	1.1	2.9	1.7	1.7	1.2	0.7	0.1	0.1	0.1

C

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.1	5.7	10.4	14.4	16.8	36.2	19.5	13.7	9.4	7.6	6.2	5.2	4.7
1	5.7	10.4	14.4	16.8	36.2	19.5	13.7	9.4	7.6	6.2	5.2	4.7
5	5.7	10.4	14.4	16.8	36.2	19.5	13.7	9.4	7.6	6.2	5.2	4.7
10	5.7	10.4	14.4	16.8	35.9	19.5	13.7	9.4	7.6	6.2	5.2	4.7
15	5.7	10.4	14.4	16.3	34.5	19.0	13.7	9.4	7.6	6.1	5.2	4.7
20	5.6	10.3	14.3	15.9	33.1	18.7	13.6	9.3	7.5	6.1	5.2	4.7
30	5.6	10.2	14.2	15.2	30.8	17.9	13.4	9.2	7.4	6.0	5.1	4.6
40	5.4	10.0	13.8	14.4	27.8	17.1	12.9	8.9	7.2	5.8	5.0	4.5
50	5.1	9.6	13.2	13.6	26.0	16.1	12.2	8.4	6.8	5.5	4.7	4.2
60	4.5	8.8	12.0	11.9	21.8	14.3	10.7	7.4	6.1	4.9	4.2	3.8
70	3.8	7.6	10.4	10.4	18.7	12.5	9.1	6.3	5.1	4.2	3.5	3.3
80	2.9	5.8	7.9	8.1	14.0	9.6	6.8	4.9	4.0	3.2	2.8	2.5
85	2.5	4.8	6.4	6.8	11.4	8.1	5.8	4.2	3.4	2.8	2.4	2.2
90	2.2	4.0	5.2	5.6	9.8	6.7	5.1	3.7	3.1	2.5	2.1	2.0
95	1.9	3.2	4.1	4.5	7.2	5.5	4.5	3.3	2.7	2.2	1.9	1.7
99	1.8	2.7	3.4	4.0	6.1	4.8	4.2	3.1	2.6	2.1	1.8	1.7
99.9	1.8	2.7	3.4	4.0	6.1	4.8	4.2	3.1	2.6	2.1	1.8	1.7

D

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.1	6.08	9.96	24.13	17.82	15.69	17.64	15.25	8.94	6.70	3.67	1.48	0.80
1	5.97	9.74	23.07	17.33	15.48	17.31	14.92	8.94	6.54	3.59	1.48	0.76
5	5.49	8.78	18.39	15.17	14.54	15.82	13.48	8.92	5.80	3.25	1.47	0.57
10	4.89	7.57	12.53	12.47	13.36	13.95	11.67	8.89	4.88	2.83	1.45	0.33
15	4.10	6.44	10.71	10.89	13.09	13.43	10.84	8.60	4.52	2.37	1.24	0.24
20	3.26	5.34	10.03	9.63	13.07	13.29	10.29	8.24	4.31	1.91	0.98	0.19
30	2.69	3.08	7.99	7.93	11.58	11.68	9.77	7.94	3.88	1.58	0.69	0.15
40	2.40	2.17	6.81	6.51	10.56	9.69	9.06	7.21	3.54	1.40	0.55	0.13
50	2.13	2.05	4.93	5.63	9.73	8.25	8.35	6.72	3.37	1.25	0.47	0.12
60	1.74	1.89	2.90	5.35	8.64	7.64	7.61	6.63	3.18	1.17	0.39	0.10
70	1.07	1.58	2.07	5.04	6.93	6.82	6.01	5.33	2.68	1.06	0.29	0.08
80	0.38	1.15	1.68	4.25	4.43	4.69	3.78	2.36	1.86	0.91	0.20	0.08
85	0.28	0.65	1.58	3.90	3.65	3.84	3.73	2.11	1.64	0.89	0.16	0.08
90	0.21	0.26	1.39	3.62	3.02	3.03	3.48	1.83	1.39	0.79	0.12	0.08
95	0.20	0.25	0.90	3.54	2.97	2.31	2.52	1.47	1.02	0.43	0.09	0.07
99	0.19	0.25	0.52	3.47	2.93	1.73	1.76	1.19	0.73	0.15	0.07	0.06
99.9	0.19	0.24	0.43	3.46	2.92	1.60	1.59	1.12	0.67	0.08	0.06	0.06

non-flow environmental variables for the holistic e-flows framework by completing the PROBFLO EFA Tool front-end questionnaire (example content in Table 2). This application has been developed to be user friendly and provides users with a drop-down selection to describe the states/conditions for each input variable (Table 2 and Figure 3). The options selected for each stressor or system driver includes an appropriate data distribution that represent the condition of the selection for the assessment. The front-end selection is transferred into an input distribution (see annexure), which is automatically converted into a BN file representing associate input node distributions. Each drop-down list only has four options, for example, Natural, Small change, Mode, Moderate change or Unacceptable. These options are comparable to the Netica ranking scheme established for the PROBFLO Limpopo e-flow assessment (O'Brien et al., 2022) (see annexure).

Table 2: PROBFLO EFA Tool front end list of variables and associated questions to describe the environmental variables associated with an hydrology scenario that will be tested with the hydrology assessment.

NETICA NODE NAME	ECOSYSTEM SERVICE QUESTIONS
WATER QUALITY INPUTS	
State of WQ for ecosystem.	Is the water quality acceptable for the ecosystem?
State of WQ for human consumption.	Is the water quality acceptable for the people?
State of WQ for livestock.	Is the water quality acceptable for the livestock?
Treatment of WQ for human consumption.	What treatment of water quality occurs to mitigate effects of poor water quality for human consumption?
FISH QUALITY INPUTS	
Potential for ecological importance and sensitivity of fish communities.	What is the potential for high diversity of fishes and species with conservation importance, relative to natural assemblages?
Threat of alien competing species.	How much competition is there for fish from alien species?
Threat of alien predatory species.	How much predation of fish occurs from alien species?
Presence of and size/ impact of physical barriers.	How many barriers and what is the threat of barriers to fish movement/migration?
INVERTEBRATE INPUTS	
Potential for ecological importance and sensitivity of macroinvertebrate communities.	What is the potential for high diversity of macroinvertebrates and species with conservation importance, relative to natural assemblages?
Threat of alien competing species.	How much competition is there for alien species?
Threat of alien predatory species.	How much predation of fish occurs species?
Presence of and size/ impact of physical barriers.	How many barriers and what is the threat of barriers to macroinvertebrate movement/ migration?

NETICA NODE NAME	ECOSYSTEM SERVICE QUESTIONS
VEG INPUTS	
Potential for ecological importance and sensitivity of riparian vegetation communities.	What is the potential for high diversity of riparian vegetation species and species with conservation importance, relative to natural assemblages?
Threat of alien competing species.	How much competition is there for riparian vegetation from alien species?
Potential for livestock of local human communities to occur/use river.	What is the potential for vegetation for livestock to occur at the site?
Threat of predatory species.	Are there predators that pose a threat to livestock?
WATER BORNE DISEASE (WBD) INPUTS	
Potential for the occurrence of WBD vectors.	What is the potential for water-borne disease to occur?
Potential for human communities that are vulnerable to WBD.	What is the possibility of human communities to occur that will be affected by water-borne disease?
Intervention/mitigation measures for WBD.	Does human intervention occur to stop water-borne disease?
Potential for predators of WBD.	Are there predators of water-disease vectors?
RESOURCE RESILIENCE	
Potential for resource resilience to occur	What is the potential for resource resistance to occur?
How have flow durations changed.	Has the duration of flow events (base flows, freshets and floods) changed?
FLOOD ATTENUATION	
Potential for natural features to attenuate floods.	What is the potential for flood attenuation to occur?
Potential for artificial features to attenuate floods.	Are upstream mechanisms in place to control floods?

Table 2 (cont).

NETICA NODE NAME	ECOSYSTEM SERVICE QUESTIONS
RIVER ASSIMILATION	
Potential for resource assimilation to occur.	What is the potential for the river to assimilate pollution?
SOCIAL INPUTS	
Potential for tourism to occur.	What is the tourism potential in the area?
Potential of tourists to access river.	Is access available for tourism?
Potential for recreational and spiritual activities.	What is the potential for recreational and spiritual activities to occur?
Potential for wildlife to threaten tourists.	Is wildlife a threat to recreational and spiritual activities?
OTHER	
Potential for disrupted sediment supply from poor land use activities.	Has land use attributed to sediment supply?
Demand for water by human communities.	What is the demand for domestic water?
Contribution of ground water to human community needs.	Does groundwater flows contribute to domestic water supply?
State of seasonality of freshets/floods.	How has seasonality changed freshets?
State of seasonality of base river flows.	How has seasonality changed base flows?

The foundation of the PROBFLO EFA Tool includes selected ecological and social indicators of altered volume, timing, duration and frequency of flows. Some of these socio-ecological variables components (or nodes in the BNs) and flow specific, such as seasonality of freshets/floods which can be manually adjusted to in the model for scenario evaluations (Table 1). The majority of flow/ecosystem and flow/ecosystem service relationships established during the e-flow determination of the PROBFLO Framework have been established by specialists and these nodes directly query the hydrology of a scenario included in the assessment in the form of a flow duration table (Table 1). The PROBFLO EFA tool requires a user to establish a flow duration table for a scenario in Microsoft Excel ®. This table must be uploaded to the PROBFLO EFA Tool as a part of the Front-end of the Tool (Figure 4). The PROBFLO Application Tool automatically queries the flow duration table to populate/represent yearly discharge, flood discharge range, high and low flow discharge distributions. These flow attributes of a scenario have a range of flow-velocity and depth, flow-cover, flow-dilution, flow-

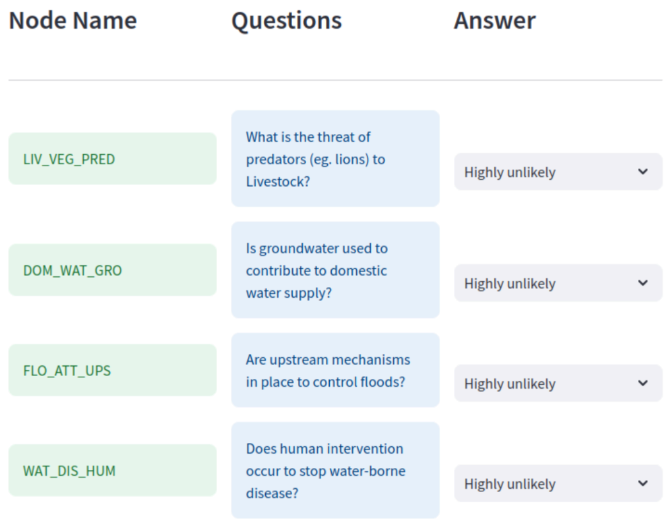


Figure 3: Screenshot example PROBFLO EFA Tool front end variables, associated questions to describe the environmental variables associated with an hydrology scenario with the drop-down box for selection.

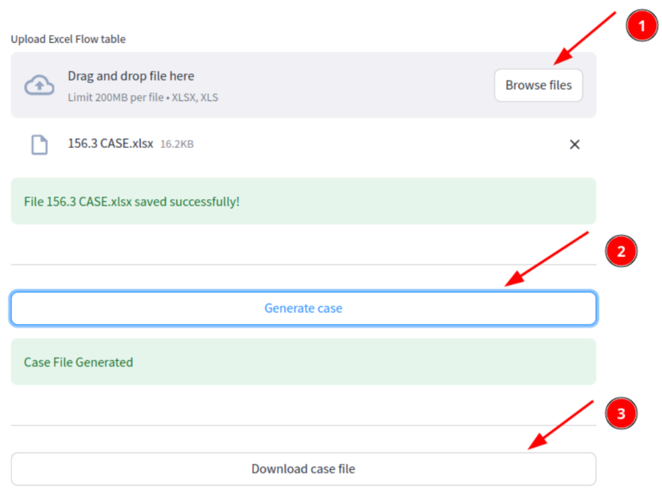


Figure 4: Example of the 1. Browsing and uploading file, 2. Generating case, 3 Download case file.

ecological cue relationships that are built into the PROBFLO EFA Tool by specialists.

The next step of the PROBFLO EFA Tool involves saving and uploading the scenario case file for the PROBFLO Framework scenario assessment. The PROBFLO EFA Tool allows you to view generated case files at any time by navigating to the Graphs tab (Figure 5) Uploading and viewing the results.

The PROBFLO EFA Tool outputs are generated automatically and include risk probability distributions for all the endpoints considered in the PROBFLO Framework (Figure 6). Endpoints can only include those selected for the PROBFLO Framework. In this example case the endpoints available include:

Supporting services:

- Risk to fish community (FISH_ECO_END).
- Risk to riparian vegetation community (VEG_ECO_END).
- Risk to macroinvertebrate communities (INV_ECO_END).

Provisioning Services:

- Risk to the provision of vegetation for subsistence harvesting of local human communities (SUB_VEG_END).
- Risk to the provision of fish for subsistence of local human communities (SUB_FISH_END).
- Risk to the availability of grazing for the livestock of local human communities (LIV_VEG_END).
- Risk to the availability of and condition of water for domestic use (DOM_WAT_END).

Regulatory Services:

- Risk to the potential for the river to attenuate floods (FLO_ATT_END).
- Risk to the potential for the river to assimilate wastes (RIV_ASS_END).
- Risk of water borne diseases occurring and impacting on human communities (WAT_DIS_END).
- Risk to the potential for the river to be resilient to change (RES_RES_END).

Cultural Services

- Risk of the river providing suitable habitat and safety for human communities to carry out spiritual activities in the river (REC_SPIR_END).
- Risk of the river providing wildlife and access to tourism activities (TOURISM_END).

An example of the PROBFLO EFA Tool outcomes is in Figure 7. The PROBFLO EFA Tool provides risk distributions for all 13 ecosystem service endpoints including the medium probability (%) representing a "threshold of potential concern" probability, and a high risk representing "probability of failure or unsustainable conditions". These outcomes provide a range of information including for example (in order of importance): (1) the probability of high risk to any endpoint, (2) the most likely risk state for a scenario, (3) the probability of the endpoint of the river being in a moderate (med) or (threshold of potential concern) state, and (4) knowledge of the certainty/uncertainty associated with the risk probability distribution.

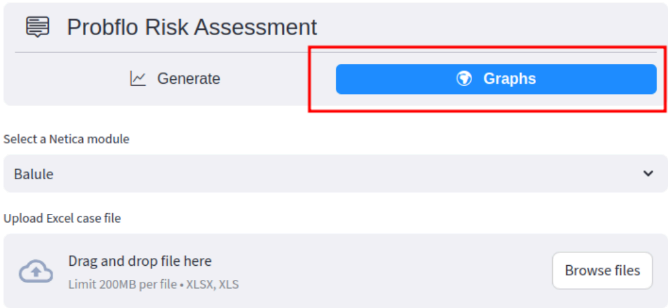


Figure 5: Navigating to graphs tab.

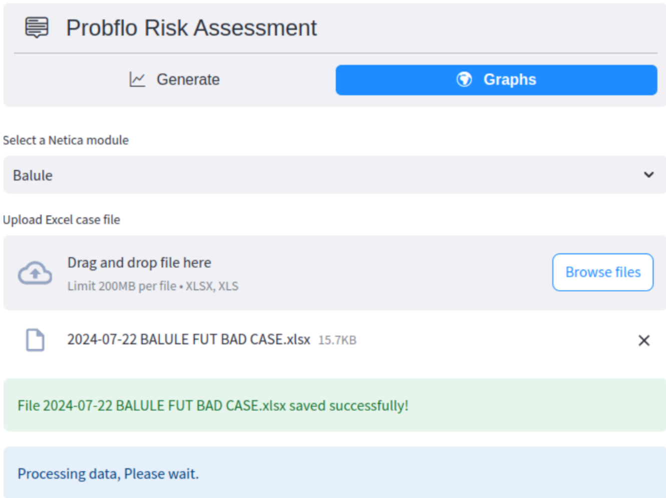


Figure 6: Uploading and processing case file to generate risk results.

In the example provided (Figure 7) representing the natural scenario for a reach of the lower Olifants River, the following information for this scenario is available:

- Probability of high risk: under natural conditions, prior to the development of the water resources associated with the Olifants River the provision of water for domestic use to human communities, water disease potential and recreational/spiritual activities and tourism were all in a high-risk state. These high-risk dominated distributions include the potential for high risk to these end points to range between (35% and 51%). This is important and quickly identified provisioning, regulatory and cultural service attributes of the ecosystem that would be of concern. These results are attributed to the natural/pre-development state of the Olifants River (O'Brien et al., 2022). These variables are in a high-risk category as there is no infrastructure to provide water to human communities and in this area communities were very vulnerable to water borne disease and predation from Crocodiles. Crocodiles also threatened spiritual and recreational activities in this area. Figure 7 and Figure 8 include demonstration of use of PROBFLO EFA Tool to generate "Natural" and "Present" scenarios. To highlight the value of the outcomes of the study and demonstrate the PROBFLO EFA Tool, you can see the considerable contrast between the potential for high risk to the supporting service endpoints between the "Natural" (Figure 7) and "Present" state scenario (Figure 8).
- Most likely risk state: Here we have an opportunity to consider the shape of the risk distributions and can see that while the water for domestic use by human communities, water disease potential and recreational/spiritual activities and tourism will probably be in a high-risk state, the fish, invertebrates and riparian vegetation communities (representing the supporting services) will probably be in a zero risk state. These results are consistent with the natural scenario. In Figure 9 (A-D) we demonstrate the flexibility of the tool to include and test different input distributions to improve confidence of the analysis while allowing uncertainty associated with input knowledge. Here we demonstrate the use of high likelihood distributions for "zero", "low", "moderate" and "high" risk dominated distributions instead of using 100% zero, low, med or high. Note these "normal" distributions (including left or right skewed distributions) are expected but the model has the ability to analyse unusual distributions including bi-modal (Figure 9E) and uniform (Figure 9H) distributions are possible.
- The probability for the "threshold of potential concern" state is then an important consideration. In a PROBFLO Framework the potential for moderate (med) risk is important as it is indicative of a socio-ecological endpoint of a scenario that could identify an ecosystems service attribute that may soon deteriorate into a high-risk state. In this case study there are no profiles with the moderate risk state dominating the distribution. In Figure 9C, an example of a moderate dominated risk distribution is provided to demonstrate where risk is probably to result in a moderate state. These outcomes can be acceptable (for example e-flows targeting "altered" but acceptable/sustainable state) but should be allowed with caution as the potential for high risk is still high.
- Certainty/Uncertainty: Apart from the formal model sensitivity/uncertainty assessment that is undertaken in Netica directly to evaluate model structure and node contribution to risk, any additional uncertainty associated with the availability of, collection and use of data for the assessment is provided in the PROBFLO report. Here certainty/uncertainty in the outcomes are additionally available in the form of the shape of the distributions considered. In Figure 9E-H, examples of differences in the confidence of results are provided including the potential for a unimodal risk distribution shape with an unusually high potential (30%) fork and high risk (35%). With these types of outcomes, more information is usually needed to improve our understanding of a potential high risk to the endpoint. Now compare the example distributions in Figure 9F, G, and H, where certainty/uncertainty associated with the distributions are comparable. Consider first, that while in Figure 9F results include a high relatively confident possibility of a moderate risk outcome, Figure 9H includes an equally uniform possible outcome of a zero, low, moderate and high risk state. This Figure 9H distribution suggests that there is either an equal chance of each state (unlikely) or there is insufficient data to result in a state dominated distribution. Compare also the distribution between Figure 9H, G and F. Figure 9G, which includes a low confident outcome with an elevated potential for a low and moderate risk (30% each) demonstrating some confidence in the distribution (compared to Figure 9H). On the occasion when limited data and or a poor understanding of the variables and flow-ecosystem or flow-ecosystem service relationships is included in an assessment, e-flow monitoring and implementation and increase certainty and the distribution could shift towards a more confident shape comparable to Figure 9B or C for example. This is the value of implementation and or monitoring using the PROBFLO EFA Tool.

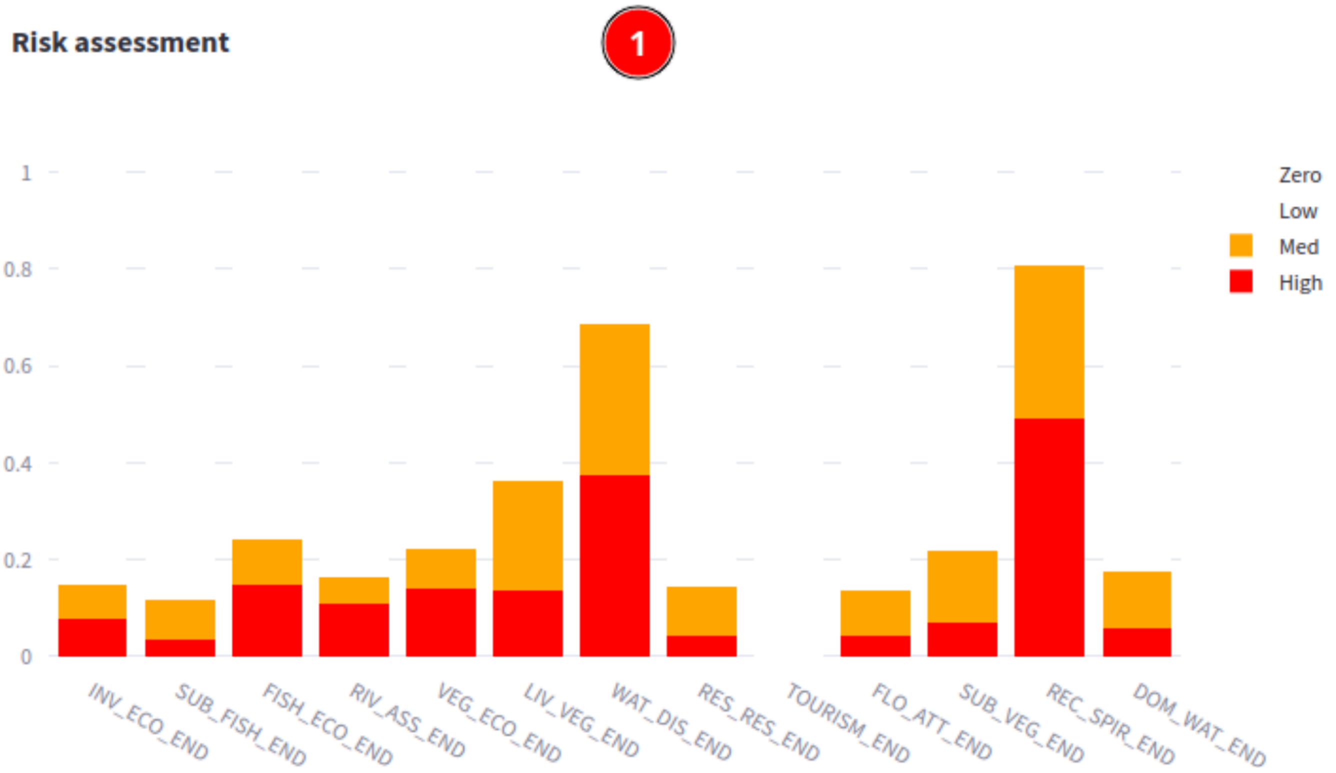


Figure 7: PROBFLO EFA Tool used to generate risk to ecosystem services using the "natural state" scenario for the supporting services alone.

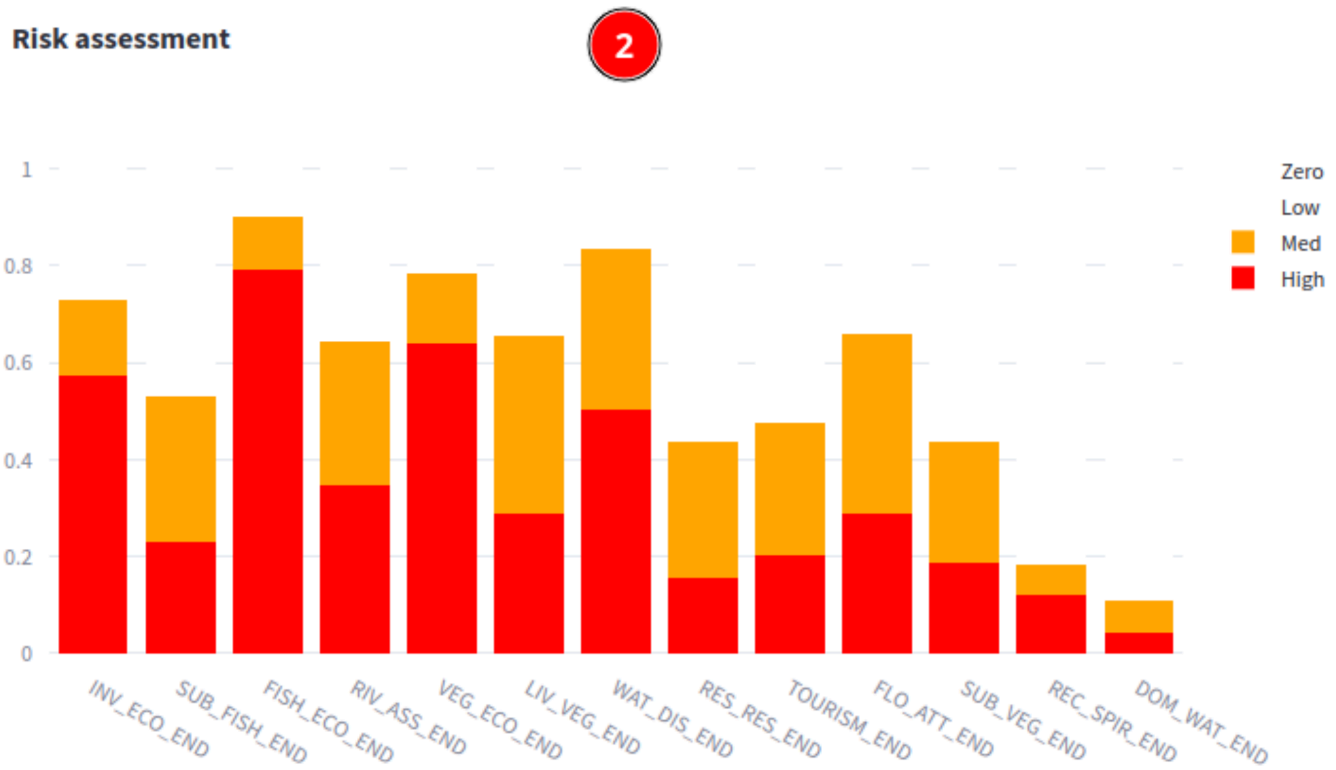
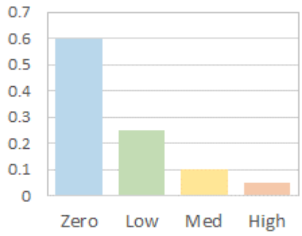


Figure 8: PROBFLO EFA Tool used to generate risk to ecosystem services using the "present state" scenario for the supporting services alone.

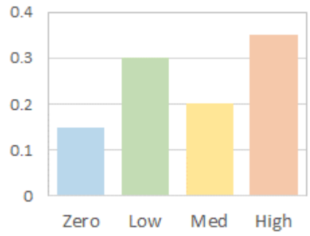
A.

Category (state)	Value (%)
Zero	0.6
Low	0.25
Med	0.1
High	0.05



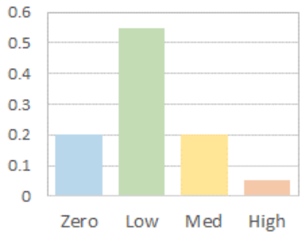
E.

Category (state)	Value (%)
Zero	0.15
Low	0.3
Med	0.2
High	0.35



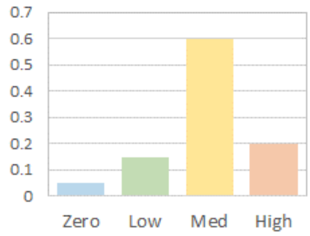
B.

Category (state)	Value (%)
Zero	0.2
Low	0.55
Med	0.2
High	0.05



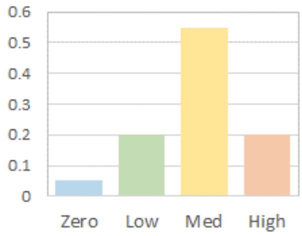
F.

Category (state)	Value (%)
Zero	0.05
Low	0.15
Med	0.6
High	0.2



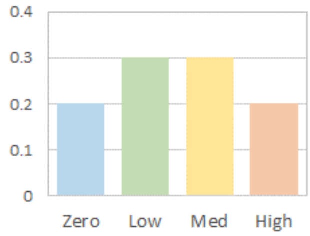
C.

Category (state)	Value (%)
Zero	0.05
Low	0.2
Med	0.55
High	0.2



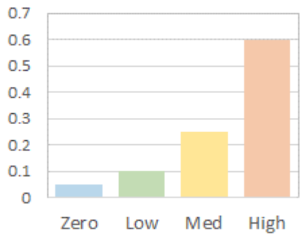
G.

Category (state)	Value (%)
Zero	0.2
Low	0.3
Med	0.3
High	0.2



D.

Category (state)	Value (%)
Zero	0.05
Low	0.1
Med	0.25
High	0.6



H.

Category (state)	Value (%)
Zero	0.25
Low	0.25
Med	0.25
High	0.25

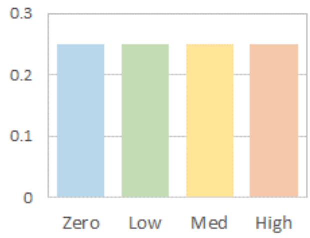


Figure 9: PROBFLO EFA Tool examples of risk profile to demonstrate potential likelihood of "zero"(A), "low" (B), "moderate" (C) and "high" (D) occurring, and the confidence uncertainty associated with varying risk distributions (E-H).

CONNECTING THE LIMPOPO DIGITAL TWIN TO THE PROBFLO EFA TOOL

To support the integration between the Limpopo Digital Twin (LDT) and the PROBFLO EFA Tool, the SWAT Extraction Tool (Figure 10) was developed as part of the LDT to provide the hydrological data necessary for running simulated scenarios within the PROBFLO framework. This tool, facilitated by an API connected to the LDT database, allows users to retrieve SWAT-simulated flow data for specific channels within the Limpopo River Basin. The data is classified into hydrological categories such as drought, normal, or wet years, based on flow percentiles. This classification assists users in evaluating various hydrological scenarios, enabling the PROBFLO EFA Tool to simulate potential impacts of different flow conditions on socio-ecological systems.

For instance, this integration could be particularly beneficial in assessing the future impacts of new water use licenses. By incorporating these licenses into SWAT simulations, users can evaluate how increased water extraction or altered flow regimes might affect the basin's hydrology under different conditions, such as drought or wet periods. The PROBFLO EFA Tool can then take these hydrological scenarios and assess the associated socio-ecological risks, providing water resource managers with a clear understanding of how such changes may impact ecosystem services. This capability may allow water resource managers to make informed decisions about water use allocations, balancing the needs of human use with the protection of ecological integrity.

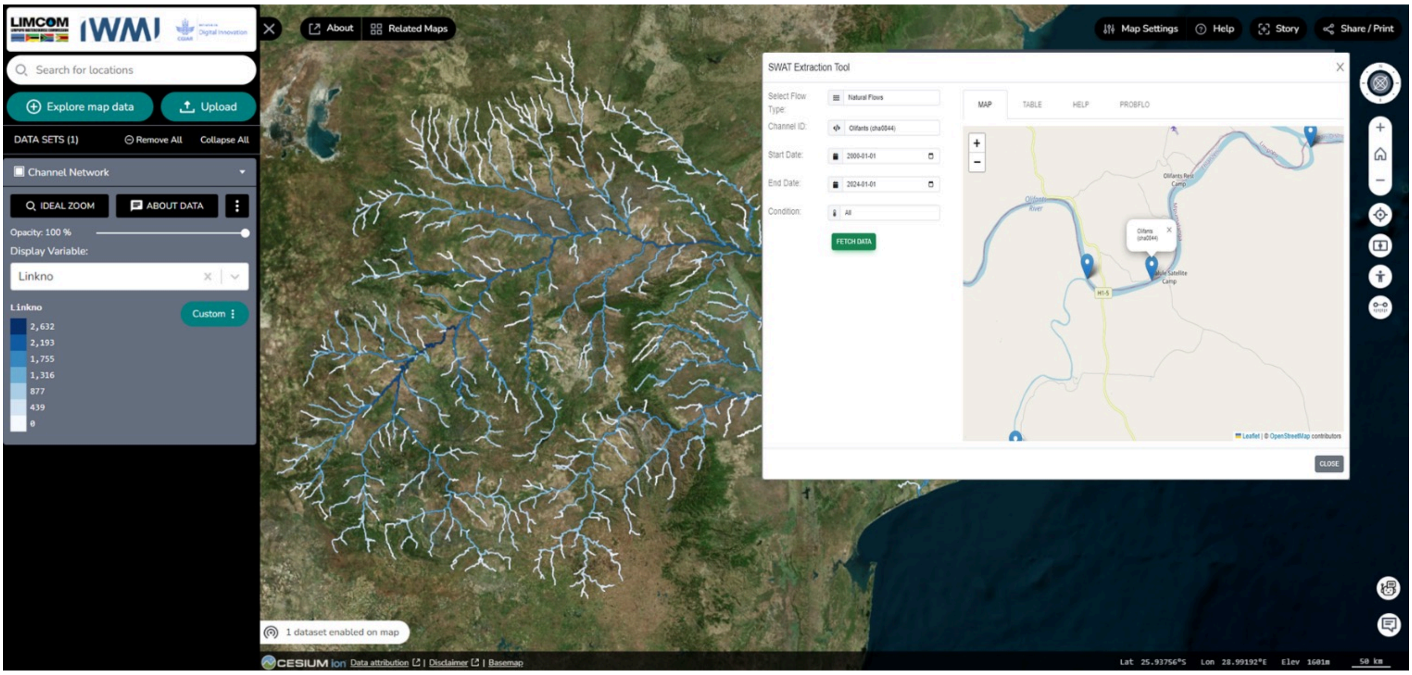


Figure 10: The Limpopo Digital Twin showing all the SWAT channels and the SWAT extraction tool which facilitates the extraction of SWAT hydrological data from the Limpopo Digital Twin

The process begins in the Digital Twin with users selecting a flow type (natural or present-day), inputting or selecting a channel ID, start and end dates, and optionally filtering the data based on hydrological conditions (drought, normal, wet) (Figure 11). The API then queries the SWAT database, extracting discharge data for the specified parameters.

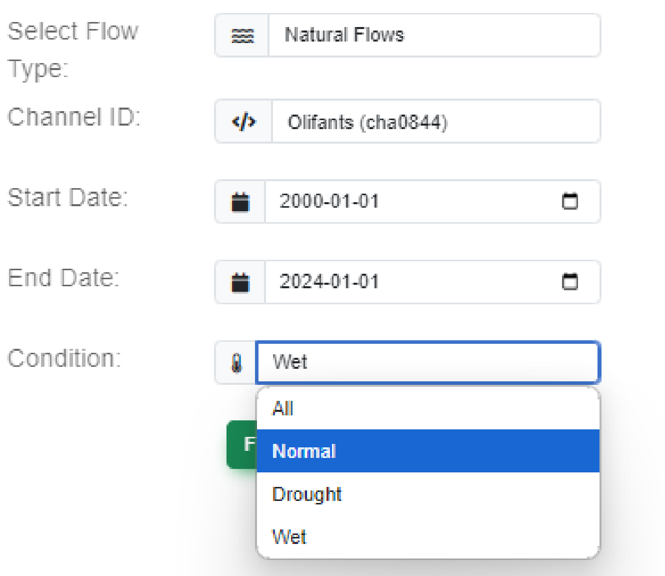


Figure 11: Fields required by the extraction utility.

Hydrological Year Classification

For the integration of the PROBFLO EFA Tool into the Digital Twin a range of hydrological statical considerations are made. This includes consideration that in southern Africa hydrological year periods are from October 1st to September 30th to align with seasonal flow patterns in the basin. The total annual discharge is calculated for each hydrological year, and years are classified into three categories based on percentile thresholds:

- Drought years: Defined as those with a total annual discharge below the 40th percentile.
- Normal years: Defined as those with a total annual discharge between the 40th and 60th percentiles.
- Wet years: Defined as those with a total annual discharge above the 60th percentile.

Then mathematically, for a given year Yi with total annual discharge Qi the thresholds drought Tdrought and wet Twet are calculated as:

$$T_{drought} = P_{40}(Q)$$

$$T_{wet} = P_{60}(Q)$$

Where $P_x(Q)$ represents the percentile of the annual discharge distribution Q. Years are classified based on whether Q_i falls below $T_{drought}$ between $T_{drought}$ and T_{wet} or above T_{wet} .

Flow Duration Curves

For each month, flow exceedance probabilities (percentiles) are calculated to construct flow duration curves (FDCs), providing insight into the distribution of discharge over time. The SWAT Extraction Tool calculates exceedance probabilities for the following percentiles: 0.1, 1, 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 85, 90, 95, 99, and 99.9. These percentiles indicate the percentage of time a particular flow is exceeded, offering a detailed characterization of flow regimes under different hydrological conditions.

For a given set of monthly discharge data D_m the exceedance probability $P_e(x)$ at percentile x is given by:

$$P_e(x) = P_{100-x}(D_m)$$

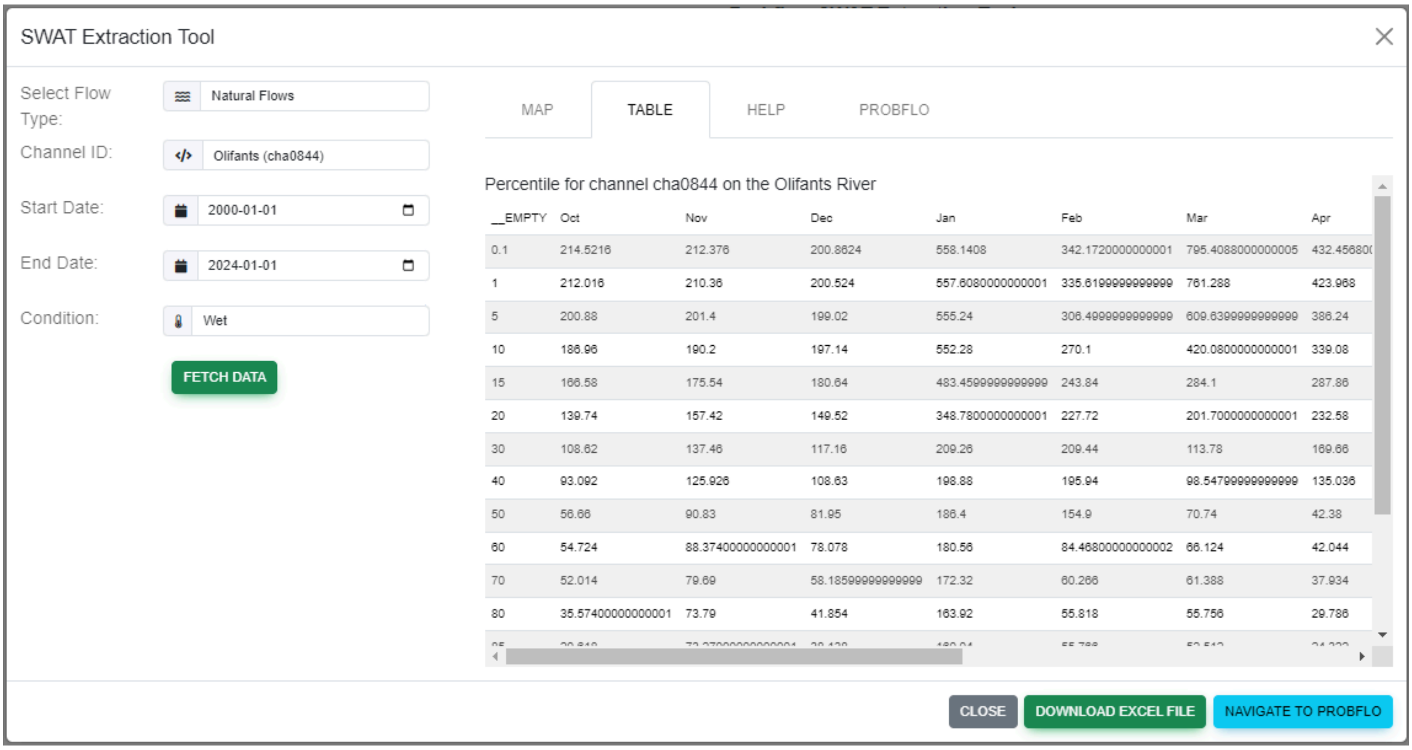
Where $P_{100-x}(D_m)$ is the reversed percentile of the discharge distribution (D_m).

Once classified and processed, the data is made available for export as an Excel file, which users can download directly through the interface (Figure 12). This exported data is structured in a format compatible with the PROBFLO EFA Tool, enabling seamless integration for further analysis and scenario testing. By leveraging the SWAT Extraction Tool within the Digital Twin, the PROBFLO EFA Tool can utilize SWAT-derived hydrological data to construct scenarios related to changes in hydrology as simulated by the underlying SWAT model; currently, both naturalized and present-day scenarios are accessible.

DISCUSSION

Flow regimes are a key driver of rivers that have been altered considerably (Bunn and Arthington, 2002). In an ideal world, flow regimes would maintain natural variability patterns to sustain the ecological integrity of the aquatic ecosystem (Horne et al., 2017). This not possible as water is needed to sustain not just human life but also world economies. It is therefore important to establish a shared vision for a river system that considers both the use and protection of the water resources (King and Brown, 2006; Wade et al., 2021) and then to establish e-flows that will meet the agreed protection requirements. While some rivers may have a higher use than others, the use should not alter the ecological integrity of the aquatic ecosystem that it reaches a seriously or critically modified state. For the Limpopo basin, the vision was for the e-flows to meet user and environmental water requirements so that the system can continue providing supporting, provisional, regulatory and cultural ecosystem services (O'Brien et al., 2022).

Globally e-flow approaches are contributing to sustainability by showing water users, regulators and conservationists what rivers require for sustainability (Arthington et al., 2023). E-flow frameworks that expand on ecosystem requirements to consider social endpoints provide users with a more holistic indication of the ecological consequences of altered flows and risk to cultural, supporting and provisioning ecosystem services. These frameworks also offer stakeholders with



__EMPTY	Oct	Nov	Dec	Jan	Feb	Mar	Apr
0.1	214.5216	212.376	200.8624	558.1408	342.1720000000001	795.4088000000005	432.45680(
1	212.016	210.36	200.524	557.6080000000001	335.6199999999999	761.288	423.968
5	200.88	201.4	199.02	555.24	306.4999999999999	609.6399999999999	386.24
10	186.96	190.2	197.14	552.28	270.1	420.0800000000001	339.08
15	166.58	175.54	180.64	483.4599999999999	243.84	284.1	287.86
20	139.74	157.42	149.52	348.7800000000001	227.72	201.7000000000001	232.58
30	108.62	137.46	117.16	209.26	209.44	113.78	169.66
40	93.092	125.926	108.63	198.88	195.94	98.5479999999999	135.036
50	56.66	90.83	81.95	186.4	154.9	70.74	42.38
60	54.724	88.3740000000001	78.078	180.56	84.4680000000002	66.124	42.044
70	52.014	79.69	58.1859999999999	172.32	60.266	61.388	37.934
80	35.5740000000001	73.79	41.854	163.92	55.818	55.756	29.786

Figure 1:2 SWAT Extraction tool interface showing the table of processed monthly duration curves.

opportunities to consider the contribution of non-flow related stressors that drive ecosystems. Together holistic e-flow frameworks like PROBFLO have been contributing to the sustainable development, use and protection of rivers on differing spatial scales from local river reach to basin scales in Africa and the world (O'Brien et al., 2018; 2020). For this study the PROBFLO EFA tool was developed and tested using the risk framework developed for the Balule site on the Olifants River as part of the Limpopo River e-flow assessment (O'Brien et al 2022). The PROBFLO EFA tool represents the first opportunity for lay stakeholders of the water resources in the Limpopo River Basin to access the PROBFLO e-flow framework set up and tested for the formal e-flow determination for the Limpopo River. This has and can still be provided by the PROBFLO EFA specialist team but now can also be provided to users through the user-friendly PROBFLO EFA Tool. Stakeholders can use the models themselves to re-run the scenarios used in the formal e-flow assessment giving stakeholders an improved opportunity to understand the input and process of the risk assessment. Stakeholders can also test altered states of multiple input variables including flow and non-flow variable and the contribution of different scenarios of resource use associated with past and present use or protection plans. Stakeholders can also use the formal risk assessment framework to test any proposed balance between the use and protection of water resources towards sustainability. This represents a massive improvement in the potential for stakeholders to engage with and use e-flow frameworks.

The PROBFLO EFA tool has been designed with a user friendly front-end that has been tested with stakeholders to allow them to change or test unique scenarios that they may be are interested in. Users can test the variability of scenarios by changing river flows or water quantity (hydrology), water quality and other environmental driver states/conditions (changes in barriers, climate characteristics and or alien invasive species impacts etc.) that may affect risk projections. These new queries and associated system driver states contribute to a scenario being considered which is automatically applied to the existing e-flows framework BN models through the PROBFLO EFA Tool. Outputs include the risk of probable risk or harm to the socio-ecological endpoints, which is automatically generated.

The integration of the SWAT Extraction Tool into the LDT serves as a link between the broader digital twin framework and the PROBFLO EFA Tool. By facilitating the retrieval of SWAT-simulated flow data for specific channels within the Limpopo River Basin, the SWAT Extraction Tool supplies the necessary SWAT derived hydrological data required for the risk assessments performed by the PROBFLO EFA Tool. This data includes the classification of hydrological conditions such as drought, normal, or wet years based on flow percentiles, ensuring that the EFA Tool operates with relevant input data derived from an operational SWAT model.

While the SWAT Extraction Tool plays a supportive role, the PROBFLO EFA Tool is responsible for the core assessment of socio-ecological risks. The extraction tool provides a way for users to input hydrological scenarios into the PROBFLO framework and assess their potential impact on ecosystem services. This user-friendly integration improves access to flow data, enhancing the practical utility of the LDT and EFA Tool for environmental flow management.

Additionally, the SWAT Extraction Tool simplifies the process of data retrieval, allowing stakeholders to focus on scenario analysis and risk projection within the PROBFLO EFA Tool. By streamlining the extraction and processing of hydrological data, the SWAT Extraction Tool supports broader engagement in water management decisions, though its primary role is to feed the necessary data into the PROBFLO framework. This integration complements the overall functionality of the LDT, while ensuring the PROBFLO EFA Tool remains the central mechanism for evaluating hydrological conditions and ecological outcomes.

CONCLUSION

This study describes the development of and testing of the PROBFLO EFA tool or IOT application developed and tested for stakeholders of sustainable water resources to access and use e-flow frameworks. The PROBFLO EFA tool makes use of RRM-BN risk models developed as a part of formal e-flow assessments. The application includes the Norsys Netica API with additional Microsoft Excel ® integration. The model includes a front-end where users can modify e-flow risk framework flow and non-flow input variables and delivers probable risk of socio-ecological risk projections for the river being assessed. This tool has been used to contribute to the sustainable management of water resources in the Limpopo River and with the application is now available for stakeholders, regulators and conservationists to engage with the e-flow framework. The stakeholders can determine the ecological requirements of rivers, and consider social endpoints for a more holistic assessment of the socio-ecological consequences of altered flows to ecosystem services. Stakeholders can now use the formal risk assessment framework to test any proposed balance between the use and protection of water resources towards sustainability. This represents a massive improvement in the potential for stakeholders to engage with and use e-flow frameworks.

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ANNEXURE

Architecture summary and setup guide

Backend

- Programming Language: Python, C, Docker
- Web Framework: Streamlit
- Version Control: GitHub

Frontend

- Languages: JavaScript, HTML, CSS

Prerequisites

Before setting up the project, ensure that the following prerequisites are installed:

1. Docker – Guide HERE

Setup

1. Clone repository

```
git clone https://github.com/PineApple-Logic/Probflo.git
```

2. Build docker image

```
cd Probflo
docker build -t netica-probflo .
```

3. Run the docker image

```
docker run -m 4g -c 4 -p 8502:8501 -d --restart unless-stopped netica-probflo
# Change the -m (memory) -c (cpu) values as needed.
```

Technical summary

Backend

The backend consists of Python scripts to handle data manipulation and sanitisation, as well as two modules. NeticaPy3 handles Netica C API to python conversation. As well as another called Netica_Modules, its responsibility is to communicate with the previously mentioned module, acting as a mediator between Netica API and python. These two modules are the wrappers used to convert the C API to be more compatible with python.

Frontend

This portion consists of two pages and the use of a library called Streamlit. This library uses predefined page format with large customisability, its main purpose is to effectively develop a webpage, compared to more traditional means, as speculated in their documentation.

Deployment

The application was contracted with the intention of been run on a virtual Linux environment, this was achieved with the use of Docker. Allowing conisitant success of deployment with a decrease in setup complexity, due to DockerFile automating the setup process, without interfering with the current systems libraries and configuration.

Features

The first stage of the application is to take the complexity of Netica and simply it, by having predefined nods, with a set of four different variations of possibility per nod, that can be chosen by the user. Leading up to a flowable insertion, to set the final four nods that represent flow values. This then gets converted into a Netica case file, which the user can share or use to determine the risk.

The user then can navigate to the graphs tab, to insert the case file, generating the risks based on the predetermined Netica model, that covers the study area the user chose.

Data flow and management

Data is temporarily stored until the user Downloads the data or if the data is invalid. Thus, preventing a build-up of data. This method both secures the data and prevents it from being accessed by others.

Security features

As of current deployment, the application sits behind a proxy that also functions as a WAF (Web application firewall). The application was constructed with user sanitisation in mind. Creating an environment, where the user's input is constraint.

Future enhancements

The application can be expanded to include a large area and be used as a risk assessment tool, with research been able to update the Netica modules to better represent catchments. Thus, constructing a web application capable of determine the current risks within a friendly user interface.