REFINEMENT OF THE REVISED DESKTOP RESERVE MODEL

VOLUME 1: RDRM REFINEMENT: BACKGROUND AND DESCRIPTION

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This report forms part of a set of two reports. The other report is Refinement of the Revised Desktop Reserve Model. Volume 2: RDRM Refinement: Manual (WRC Report No 2539/2/19).

EXECUTIVE SUMMARY

INTRODUCTION AND BACKGROUND

Overall aim of the project was to provide an updated version of the RDRM model that can estimate EWRs at a desktop level, as well as to facilitate the links between hydrology, hydraulics and ecology within more detailed EWR assessments.

The methodology was largely based on engagement between the model developer and many different key Reserve determination specialists, to develop a set of generic 'rules' for setting the parameters of the model under desktop type determination conditions (i.e. in the absence of specialist inputs). The engagement was designed to extrapolate from their experience of completing detailed assessments (intermediate and comprehensive level determinations) at specific sites to a more regionalised set of rules that can be considered applicable anywhere in the country (albeit at a lower level of confidence and higher levels of uncertainty).

This report serves as the final report of this study. The report will be provided as two volumes as follows:

- Volume 1: RDRM background and description.
- Volume 2: RDRM manual.

LOW FLOW (ECOLOGY) SUB-MODEL

The **ecological component (low-flow)** of the model relies on a relationship between flow and ecological habitat stress and it makes use of the estimations of available habitat from the hydraulics model. This component uses the fast-deep, fast-intermediate and fast-shallow habitats and the flow-stress relationship is based on how the frequencies of the habitats change with changing flow. However, the model includes parameters that are used to weight the importance of the three fast habitats depending on the presence of different species (of fish or other aquatic organisms) and their habitat requirements. In a calibration application of the model the species that are present would have been identified by ecological specialists, but in a purely desktop application this type of information is generally not known. The primary objective of this component of the current study was to incorporate available fish distribution and ecological (velocity preference) information into the ecological sub-model of the revised RDRMv2. All relevant fish and macroinvertebrate distribution data was abstracted from the latest PESEIS database (DWS). This information was used to design a “distribution model” that will function outside of the RDRM. Relevant available literature and databases were used to collate all information relevant to this study regarding the flow-preference of fish (and macroinvertebrates) of South African Rivers. The primary information used was the minimum (in terms of flow dependence) velocity-depth (VD) habitat that is required to ensure the survival/well-being of the species in a reach during the wet and dry season. Although macroinvertebrate information was considered during the initial testing it was evident that the use of macroinvertebrate information within the current format of the RDRM will not be possible. The revised RDRMv2 model therefore only utilises fish species information and in the absence of any fish information for a site/reach, the model uses conservative default values to cater for any potentially occurring fish or macroinvertebrates. One of the primary requirements in the ecological sub-model is the estimation of weights that indicate the importance of different fast velocity depth categories under different seasons (wet and dry). Various possibilities were discussed and tested during this study to determine the most effective way of utilising the relevant the fish information during this process to improve the confidence levels of these weighting at a desktop level. Various approaches were also discussed and tested as part of this study to determine the shift parameters for ecological categories (A to D).

Changes to the RDRM low flow sub-model:

- The stress flow parameters were adjusted to include new rules that reflect changes that occur in FS and FI at quite low flows.
- Ecological category stress frequency curves: Default parameters were never established with any explicit ecological meaning. The new parameter set was based on estimated actual maximum and minimum stress values for A to D categories.

Stress Weights: The stress weights are now designed to place greater emphasis on some of the fast habitats. Manual changes were built in. A system of accessing the national ecological database has also been included so that estimates of the weights for the different hydraulic habits (fast-deep, fast-intermediate and fast-shallow) can be made for most river sites in the country.

HIGH FLOW (ECOLOGY) SUB-MODEL

It is possible to adequately (taken as $R^2 > 0.8$) relate channel characteristics (such as bankfull discharge) and flow characteristics related to the channel (such as discharge at various percentiles according to exceedance values or marginal vegetation distribution, or maximum wet season baseflow) to the flood requirements as determined by riparian vegetation and to a lesser extent fluvial geomorphology. Given the profile at a site these relationships should be able to adequately define the flood requirement, and as such have potential for use within the RDRM. This was put to the test by exploring data relationships from as many as possible existing intermediate and comprehensive Reserve Determination sites. Several quantifiable relationships were useful to determine flood requirements at the desktop level. Overall the bankfull discharge most adequately described acceptable relationships for most flood frequency classes. The empirical equations for the peaks (QP) of the different flood classes are given below (MBF = maximum wet season baseflow, BFQ = bankfull discharge, CV = coefficient of variation of monthly flows of the wettest month) and are based on an analysis of previous EWR determinations in South Africa:

Class 1: $QP1 = 2.6 * MBF^{0.736}$

Class 2: $QP2 = 3.44 * MBF^{0.685} + QP1$

Class 3 (annual event): $QP2 = 4.3 * MBF^{0.6} + 0.006 * (BFQ / (1+CV))^{1.29} + QP2$

Class 4 (1:2 yr event): $QP3 = 1.47 * (BFQ / (1+CV))^{0.62} + QP3$

Class 5 (1:5 yr event): $QP4 = 2.5 * (BFQ / (1+CV))^{0.74} + QP4$

Changes to the RDRM high flow sub-model:

The high flow sub-model can be seen as a new version rather than a refinement as it differs significantly from the previous model. The new approach is explicitly linked to the hydraulics of the channel cross-sections. The default number and size of floods will be standard for all desktop applications and these will be automatically calculated but can be changed by expert users. Other than the previous version, the rules used an extensive analysis of all previous relevant EWR flood assessments.

DESIGN OF THE REFINED RDRM MODEL

The components of the model that deal with the low flow and high flow requirements have been extensively modified from earlier versions of the model. Specifically, the rule base for setting the shapes of the stress frequency curves for the different ecological categories has been better aligned to reflect recent experiences from Reserve determinations. A system of accessing the national ecological database has also been included so that estimates of the weights for the different hydraulic habits (fast-deep, fast-intermediate and fast-shallow) can be made for most river sites in the country.

The high flow requirements are now based on setting flood hydrographs (peaks and durations) for several flood classes, based on a set of equations relating the peak flow to a combination of maximum wet season baseflow, bankfull discharge and the coefficient of variation of the wet season months flow. In a truly desktop application (without a surveyed channel cross-section) these changes imply that it is quite important to get a reasonable estimate of the true channel size and hydraulic characteristics.

WAY FORWARD

One of the topics that was discussed during the workshops that were held for this project centred around the future use of the model and SPATSIM within the Department of Water and Sanitation (DWS). The key issue is that several individuals and outside organisations (consultants) could be doing Reserve determinations based on their own setups of SPATSIM, while DWS needs to maintain a central database that contains all the information and data required to repeat a run of the model for a specific site. The following recommendations are made to facilitate this process.

- Establish a position(s) within DWS for a person or persons who will be responsible for maintaining the central database.
- Any individual or organisation (remote user) tasked with doing a Reserve determination will have to obtain the current version of the SPATSIM application database from the central database administrator. This is a simple matter of copying the application (currently called Nationalv2) folder from one computer to another and can be done over the internet or locally.
- When a remote Reserve determination has been completed, the new information that has been generated is exported to text files (using the <Attribute>, <Export Attributes> menu option for all the appropriate attributes) by the remote user. The remote user then edits the exported data so that only the data for the new sites that they have generated remains. These files, as well as the locations of the new Reserve sites are then passed to the DWS central database administrator.
- The DWS central database administrator then creates the new EWR Site points (using <Features>, <Point Features>, Add Points>) with exactly the same names used by the remote user and then uses the various <Attribute>, <Import or Edit> options to import the data from the text files supplied by the remote user.

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1 INTRODUCTION

1.1 BACKGROUND

The need for a desktop level method for quantifying environmental flow requirements (referred to as the ''ecological Reserve' in South Africa) is recognised locally (Hughes and Hannart, 2004; Hughes and Louw, 2010) and internationally (Acreman and Dunbar, 2004; Smakhtin et al., 2004; Dunbar et al., 2004; Acreman, 2005; Smakhtin et al., 2006). The need for such a modelling approach was partly because specialist ecological expertise and/or data may not be available in many parts of the world and partly because of the need for rapid estimates to support water use license applications. It is simply not always practical to carry out a detailed determination, involving expensive (in time and money) field observations and analyses. While there have been several approaches suggested worldwide, within South Africa the Desktop Reserve Model (DRM: Hughes and Munster, 2000; Hughes and Hannart, 2004) has been used by the Department of Water and Sanitation for many years. The DRM was based on the Building Block Methodology and relied strongly on assumed relationships between hydrological variability and the percentage of mean annual runoff that would be required to satisfy the Ecological Reserve requirements at different levels of ecological protection. The estimation of the annual requirements was further supported by regional parameters that defined the calendar month requirements as well as the magnitude-frequency relationships that cater for variability in flow requirements between dry and wet periods.

As the whole process of setting environmental flow requirements became more sophisticated and included more science and experience from all the supporting disciplines (hydrology, hydraulics, ecology, geomorphology), so the need for a revision of the desktop approach was identified (Hughes and Louw, 2010). This research culminated in the Revised Desktop Reserve Model (Hughes et al., 2014) which attempted a more complete integration of hydrology, hydraulics and ecology, largely based on the concepts of habitat flow-stressor response. The basic concept is that the ecological response of rivers should be related to changes in available habitat that are in turn associated with the relationships between discharge (hydrology) and the characteristics of the river channel (hydraulics).

During the early days of Ecological Reserve determination in South Africa, it became abundantly clear that a desktop model not only has value for rapid (and generally low-confidence) determinations, but can also be used in more detailed (intermediate to comprehensive) determinations. For the latter, the model is used to support and integrate the information generated by the different Reserve specialists and is calibrated to meet their understanding of the ecological flow requirements. A further model (the Habitat Flow-Stressor Response model) was also developed to facilitate this process. The calibrated desktop model would therefore use the specialist inputs to generate the complete Ecological Reserve information (assurance tables and time series of Reserve requirements) that would be required either for water use licensing assessment (Hughes, 2006), for water resources yield scenario modelling, or for real-time management of the Reserve and water uses (Hughes and Mallory, 2008). Inevitably, the use of the model in a 'calibration' environment meant that additional functionality needed to be included so that a user could modify all the parameter values. In some respects, this makes the model more confusing for desktop users as there are additional user options that inexperienced users may not fully understand. In the context of the original RDM this was not a major issue as regionalised parameters were made available as part of the database and software package that included the model. The only real user intervention required was to check that the default regionalised parameters were appropriate for the specific site of interest and facilities were provided as part of the model to perform such checks. It was relatively straightforward to also offer guidelines on what to do if a user noted any serious problems with the default parameters (typically the guideline would be to choose a more appropriate region).

The situation with the revised model (RDRM) is rather different, mainly due to the added complexity associated with explicitly linking the hydrology, hydraulics and ecological stressor response information. There are many more parameters in the model that need to be set by a desktop type user, which would be calibrated by a specialist user through the application of some additional analysis procedures. Unfortunately, during the initial development of the model it was not possible to identify a satisfactory approach for regionalising these parameters. There are two specific areas in the model where establishing appropriate parameter values is not only critical for the results, but where there are no simple guidelines.

The ecological component of the model relies on a relationship between flow and ecological habitat stress and it makes use of the estimations of available habitat from the hydraulics model. This component uses so-called velocity-depth classes of fast-deep, fast-intermediate and fast-shallow habitats, and the flow-stress relationship is based on how the frequencies of these habitats change with changing flow. However, the model includes parameters that are used to weight the importance of the three fast habitats depending on the presence of different species (of fish or other aquatic organisms) and their habitat requirements. In a calibration application of the model the species that are present will be identified by ecological specialists. In a purely desktop application this type of information will almost certainly not be known, unless the model is being run by an ecological specialist with detailed knowledge of the river.

The time series of natural and present day (if available) flows are processed through the flow-stress relationship to generate time series of ecological habitat stress which are then used to display the natural and present days stress frequency curves for the critical wet and dry season months. Establishing the Ecological Reserve (for low flows) involves identifying appropriate stress curves for each of the ecological categories (A to D), which are then reverse processed through the flow-stress relationships to quantify the Reserve flow time series. It is assumed that the Reserve stress values will be generally higher than the natural stress values (i.e. lower flows), but the upward shifts from natural are controlled by a set of shift parameters for each end of the stress frequency curves (i.e. high stress, low frequency of exceedance and low stress, high frequency of exceedance). These curves are comparable to flow duration curves. The effects of changes in the shift parameter values are difficult to predict and vary with the shape and actual values of minimum and maximum stress. It is therefore extremely difficult for a Desktop user to establish what appropriate shift parameter values to use without guidance from some ecological data on the stress characteristics of the river and its biota. It was originally anticipated that these shifts could be regionalised from some knowledge of river types, typical species or other ecological information. However, these regional relationships were not forthcoming during the initial development of the model.

The estimation of the habitat weights and the stress curve shift parameters under purely desktop type applications was therefore one of the key focus areas of this research project. Various approaches were investigated, but all of them were based on prior experience of Reserve determinations (some of which have applied the RDRM through calibration) by the ecological specialists who are part of the project team. These specialists all have experience of running the ecological habitat models that are frequently used to calibrate the RDRM parameters (and the DRM model previously). Essentially, the project needed to look for mechanisms and/or patterns in the parameter estimation process that can be generalised and regionalised based on available ecological and possibly geomorphological (e.g. river type) data.

The other major shortcoming of the RDRM was the fact that the high flow component of the Reserve remains based on more or less the same approach that was used in the original DRM using simplified relationships between annual high flow volumes and an index of natural hydrological variability. It was always intended that this should be updated to make more explicit use of the channel shape and hydraulics and be more aligned to the approaches used in more detailed Reserve determinations. The basic concept was to define a range of high flow events of different magnitude and frequencies and occurring during key periods of the year that perform certain ecological functions (as defined through the hydraulics). This type of information can be regionalised given our existing knowledge and understanding of flow regimes in different climate and channel type settings within the country.

1.2 HISTORICAL CONTEXT

The Revised Desktop Reserve Model (RDRM) was developed during a WRC project which was finalised during 2011. What was highlighted at the end of this project was that the beta version required further testing and that certain components in the model required improvement, notably the lack of a link between the high flow estimates and the hydraulics of the channel cross-section, as well as more explicit inclusion of regional information about the presence of different aquatic species and how these would influence some of the model parameter settings. Since 2011 the model has been extensively used for desktop applications during Reserve and Classification studies for the Department of Water and Sanitation (DWS) and some further facilities have been added because of this experience. It has also been used as the model of choice for linking hydrological, hydraulic and ecological information within Intermediate and Comprehensive Reserve studies. While various ad hoc adjustments and improvements have been made, some of the limitations identified during 2011 still needed to be addressed if the model is to be used by a wide range of DWS (and consultant) staff. The future intensive use of the model at the true Desktop level (i.e. without experienced specialist input) and the need for some of the limitations to be addressed was highlighted during a WRC/DWS/Specialist meeting in January 2015. The outcomes of this meeting led to this study and the objective of refining the existing model and ensuring a more user-friendly format.

1.3 CONTEXTUALISATION

The project addresses sustainable development solutions (the Desktop model is used to set environmental flow requirements which is a fundamental sustainability component of the South African water management strategy). The project addressed informing policy and decision making in that the whole process of setting Ecological Reserve requirements would be extremely difficult without it. The project addressed human capital development in the water and science sectors in that it serves as a relatively easy to use introduction to the concepts of Ecological Reserve determinations, which will be useful for the graduate trainee staff of DWS. During the course of the project, three DWS trainees participated at all levels which included exposure to the development of the model as well as one on one intensive training in the use of the model.

1.4 PROJECT AIMS

The project aims were summarised as follows:

Overall aim: To provide an updated version of the RDRM model that can estimate EWRs at a desktop level, as well as to facilitate the links between hydrology, hydraulics and ecology within more detailed EWR assessments.

1.5 METHODOLOGY

The methodology was largely based on engagement between the model developer and many different key Reserve determination specialists, to develop a set of generic 'rules' for setting the parameters of the model under desktop type determination conditions (i.e. in the absence of specialist inputs). The engagement was designed to extrapolate from their experience of completing detailed assessments (intermediate and comprehensive level determinations) at specific sites to a more regionalised set of rules that can be considered applicable anywhere in the country (albeit at a lower level of confidence and higher levels of uncertainty).

The actual computer coding of the model was relatively trivial (despite the fact that the code is quite complex in some parts of the model) and is not referred to here in detail. What was more important was for the model developer and the key specialists to agree on approaches that are both scientifically appropriate (in terms of what information and methods they typically use for detailed assessments), but are also pragmatically practical to apply at the desktop level with information that will always be available. This has always been the major problem in determining the best approaches to use within a desktop model. The first version of the revised desktop model included hydraulics and the links to the hydrology (to allow for variability of hydraulic conditions over time) and the ecological response achieved the objective of scientific appropriateness in some areas, but did not adequately incorporate the basic principles of some of the methods being used at more detailed levels of determination.

Part of the reason for that was that some of these methods were still being developed and refined and there was not enough of an experience base to develop generic regional rules that could be used at the desktop level. That experience base has increased substantially over the last (approximately) 5 years, and therefore it was now possible to extrapolate to generic regionalized rules. The key issue associated with the model design methodology is therefore to get the specialists to identify what major factors determine differences in flow requirements at different sites and then to identify what information was likely to be available at the desktop level to quantify those factors. If there is likely to be no such information that is readily available, then either other factors must be used, or some suitable and available surrogates. This approach applied equally to the changes required to include high flows (linked more explicitly to the hydraulics), as well as the changes required for the ecological sub-model for low flows.

There were two parallel and complimentary processes relating to the improvement of the ecological sub-model specifically. The ecological specialists of the team looked for 'mechanistic' solutions to the parameter estimation problem, largely based on the software that they use to link hydraulics and ecological species data and supported by relevant databases of species data (some of which are available from the PES and EI-ES studies). The second process involved assessments of the model outputs applied in a desktop method with previous results that were based on specialist input, and therefore represent a re-calibration of the model. These two complimentary approaches helped in not only setting guidelines for true desktop applications, but also provided something of a reality check on each other. As already noted, sensitivity analyses of all the parameters of the model formed part of this assessment. This was clearly important as there was little point in spending large amounts of research time developing complex guidelines for parameters that are not very sensitive and that are unlikely to have much impact on the model results. However, experience (Hughes et al., 2014) suggests that it is quite important to define how to assess sensitivity. The overall low flow requirement in terms of mean annual volume may be not very sensitive to some parameter changes, while the seasonal distribution or the balance between drought and wetter period requirements might be quite sensitive and might be very important in water resources yield and management assessments.
Similar complimentary processes were required for the revised approach to the high flow estimation and flood modelling, in that the new software design should not only address the needs of the specialists using the RDRM in a detailed assessment, but should also be able to be used as a desktop model with readily available data.

Figure 1.1 summarises the project structure in a simplified manner. There was a greater degree on interaction and feedback between the different project components that are included in this simplified diagram. The technical inputs for the ecological and flood sub-models were not confined to only identifying the limitations of the existing model and compiling datasets to support future desktop applications of the model. They also had input into the revised structure of the model.

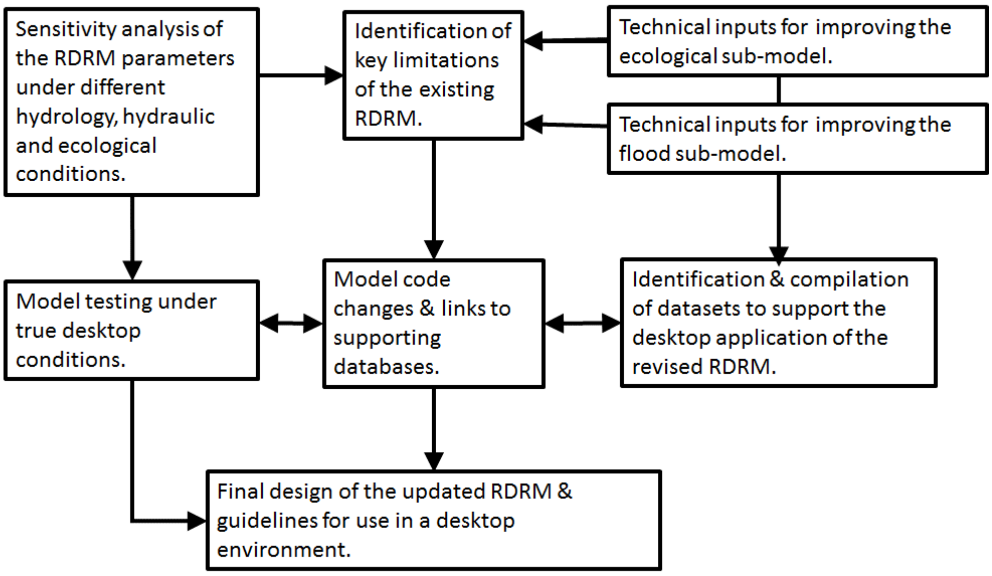

Figure 1.1 Simplified project structure

1.6 DELIVERABLE 8.2: MAIN REPORT

This report serves as the final report of this study. The report will be provided as two volumes as follows:

- Volume 1: RDRM background and description.
- Volume 2: RDRM manual.

2 ECOLOGICAL SUB-MODEL (LOW FLOWS)

2.1 OBJECTIVE

The **ecological component** of the model relies on a relationship between flow and ecological habitat stress and it makes use of the estimations of available habitat from the hydraulics model. This component uses the fast-deep, fast-intermediate and fast-shallow habitats and the flow-stress relationship is based on how the frequencies of the habitats change with changing flow. However, the model includes parameters that are used to weight the importance of the three fast habitats depending on the presence of different species (of fish or other aquatic organisms) and their habitat requirements. In a calibration application of the model the species that are present would have been identified by ecological specialists. In a purely desktop application this type of information will almost certainly not be known, unless the model is being run by an ecological specialist with detailed knowledge of the river.

The primary objectives of this phase of the project included:

- Revise and amend the ecological sub-model (low-flows) of the RDRM by incorporating relevant fish (and possibly invertebrate) information.
- Collating relevant information for instream components (fish and possibly macroinvertebrates) for use in the ecological sub-model (low flows and flood requirements) (primarily generated during the PESEIS study (DWS/WRC)
- Development of the approach for improved integration of ecological species data into the low flow estimates of the desktop model. The aim is to result in a more user friendly subcomponent which is explicit in terms of the ecological link. The following specific actions were applied:
    - Use current desktop (PESEIS database) information of fish species and invertebrate taxa distribution to determine the fish and invertebrate assemblage that can be expected at the site.
    - Use the generated fish and macroinvertebrate assemblage to determine the weightings of VD classes in ecological sub-model (used in determination of stress index).
    - Use the ecological information and rationale to determine potential shifts in ecological categories (on desktop level).
- Undertake the required testing of the ecological sub-model (which could not be done during the design of the RDRM).
    - Run the revised RDRMv2 model on various previous comprehensive reserve determination sites and utilise new ecological information in the ecological sub-model to determine whether the desktop results provide relatively similar outcomes.
- Compile a user manual for the ecological sub-model of the RDRM.

2.2 USING ECOLOGICAL INFORMATION IN ECOLOGICAL SUB-MODEL

2.2.1 Fish and Invertebrate Distribution Data

Dr Birkhead abstracted all relevant fish and macroinvertebrate distribution data from the latest PESEIS database (DWS website). The data of all secondary catchment spreadsheets was collated in a single spreadsheet for easy reference and future coding purposes. This information was used to design a “distribution model” that will function outside of the RDRM (due to the size of this data base, it will only be available electronically and incorporated (coded) into the RDRMv2). The aim of this model will be to:

- Determine the expected fish and macroinvertebrate assemblage for a specific site. This will be based on the expected species and taxon distribution information on a sub-quaternary (SQ) reach scale as contained in the PESEIS database.
- Although emphasis is generally placed on the biota present at a site under current conditions (PES) when setting flows in reserve determination studies, it was decided that at a desktop level a conservative approach should be applied. The fish species expected at the site under reference conditions that may have been lost due to anthropogenic activities was therefore also considered in the desktop reserve model. This will avoid the exclusion of important species that should be catered for when setting flows at desktop level.
- The ecological, and more specifically the requirement of the biota at the site specific flow-dependant habitats, will then be abstracted from the database, to be used to populate the ecological sub-model of the RDRM.

2.2.2 Fish and invertebrate Ecological Information (flow preference)

Relevant available literature and databases were used to collate all relevant information on the fish and macroinvertebrates of South African Rivers. The main deliverable of this phase consists of an electronic MS excel spreadsheet (RDRM_Fish-Invert Info_V3).

The primary information that was used in the ecological sub-model of the RDRM included the following:

- **Minimum/Critical VD requirement (Wet Season):** The minimum (in terms of flow dependence) velocity-depth (VD) that is required to ensure the survival/well-being of the species in a reach.
- **Minimum/Critical VD requirement (Dry Season):** The minimum (lowest flow dependent) VD that is required to ensure the survival/well-being of this species in a reach.

Other information provided as part of this deliverable (not currently used in the RDRM calculations) included:

- **Size-Flow guild category:** Each fish species is assigned to a specific size-flow guild, based on their requirement for flowing water. The following definitions were applied for the purpose of the current study:
  - Rheophilic species are defined as species with a requirement for fast (>0.3m/s) flowing habitat during all life stages.
  - Semi-rheophilic species are species with a requirement for fast flowing habitats during some life stages.
  - Limnophilic species are broadly those species that prefer or complete their life cycle broadly in slow or stagnant habitats.

- **Optimal velocity-depth preference (VD) (Wet season):** The optimally preferred velocity-depth (VD) categories of the species during the wet season (best case scenario).The following velocity-depth classes were used:
  - **Fast Very Shallow (FVS):** >0.3m/s; <0.1m
  - **Fast Shallow (FS):** >0.3m/s; 0.1-0.2m
  - **Fast Intermediate (FI):** >0.3m/s;0.2-0.3m
  - **Fast Deep (FD):** >0.3m/s;>0.3m
  - **Slow Shallow (SS):** <0.3m/s;<0.5m
  - **Slow Deep (SD):** <0.3m/s;>0.5m

- **Optimal VD (Dry season):** The optimally preferred velocity-depth (VD) categories of the species during the dry season (best case scenario).

- **Flow-requirement indicator value:** A general indication of the value (Low, Moderate or high) of a species to be used during flow determination calculations or studies.
- **Migratory requirement:** Relative requirement of a species to migrate between catchments (typical catadromous), between reaches (typical potadromous) or only within a reach. This information may be useful in checking of high flow or flood requirements during reserve studies.

Although the aim of this study was primarily to utilise available fish information, it was also attempted to investigate the requirement for inclusion of macroinvertebrate information at desktop level. As the RDRM ecological sub-model currently uses fish velocity-depth categories (fast-deep, fast-intermediate, fast-shallow) during the weighting process, the invertebrate flow-habitat requirements had to be translated into (interpreted as) fish velocity-depth (VD) classes. Although this information was valuable during this testing phase (especially sites with low fish diversity or seasonal/ephemeral systems), it was evident that more information on invertebrates will be required and further testing should be done in future. It was furthermore decided that there are limitations in the interpretation of macroinvertebrate habitats in terms of fish VD categories, as macroinvertebrate flow requirements is generally described only in terms of velocity requirement, while fish considerers velocity and depth (VD classes). The initial testing of the data also confirmed that based on the current RDRM weighting approach, the fish always have a higher requirement for flow (in terms of velocity-depth classes) than invertebrates and should hence generally address the requirements of the macroinvertebrates. In the absence of any fish information for a site/reach, the revised RDRMv2 model uses conservative default values to cater for any potentially occurring fish or macroinvertebrates.

2.2.3 Determining relative weights (importance) of velocity depth classes

One of the primary requirements in the ecological sub-model is the estimation of weights that indicate the importance of different fast velocity depth categories under different seasons (wet and dry). The best way to determine this importance is to base this on the habitat requirements of the instream biota (fish and macroinvertebrates) that can be expected at the site. Various possibilities were discussed and tested during this study to determine the most effective way of utilising the relevant the fish information during this process to improve the confidence levels of these weighting at a desktop level. Refer to section 4.3 below for a description of the final method incorporated in the revised RDRMv2 model.

Should the model detect that there is no fish in a reach/site, it will revert to using a default “invertebrate” rating. This is based on the assumption that although there may not be fish present that requires fast habitats, there may very likely be inveterate taxa with a requirement for fast habitats and that these should therefore be consider as important. The default ratings used in the model for invertebrates (if no fish present) is as follows:

Wet Stress at 0% FS:	9
Wet FS Weight:	2
Wet FI Weight:	1
Wet FD Weight:	0
Dry Stress at 0% FS:	5
Dry FS Weight:	3
Dry FI Weight:	1
Dry FD Weight:	0

2.2.4 Adjustment of default fish information

The actual fish species present along a river reach and their relative requirements or preferences for different (fast) velocity-depth classes were used to compute the relative weights of these classes and the stress at zero fast flow. These are provided in SPATSIM as attributes linked to river sub-quaternary river coverages and need to be transferred to the appropriate parameters in the desktop ecological sub-model. The user (fish specialist) may want to adjust these ‘default’ values, however, and a standalone computational procedure in a MS Excel has been provided for this purpose. The file contains three worksheets:

- for the site/s under consideration, a list of fish species presence/absence;
- fish preference ratings for different velocity-depth classes, and
- computed weights and stress at zero fast.

The (first two) worksheets have been populated with fish species information used to compute weights for the RDRMv2 but allow for additional species to be added and (weighting) computations to be performed.

2.2.5 Determining shift parameters for ecological categories (A to D)

Various approaches were discussed and tested to determine the stress ratings (at 0% and 100% flow frequency) for a category D. The rest of the categories between A and D will be calculated based on the relevant proportional percentages used in the EcoClassification methodology. A summary of the approach is provided below and the detailed explanation follows in 4.3.3.

Category D stress at 100% stress frequency:
The initial approach that was adopted was to use 50% of the maximum natural stress as the minimum stress for a D category. However, this tended to result in very low stress values for rivers with low natural stress variability and the rule was later modified to:

If the maximum natural stress ≥ 4 then the D category minimum stress = 0.5 * maximum natural stress.

If the maximum natural stress < 4 then the D category minimum stress = 2 * maximum natural stress, with an upper limit of a stress of 2.0.

Category D stress at 0% stress frequency:
The maximum stress (i.e. at 0% exceedance) is calculated as the stress at which the critical habitats almost disappear (note that the 'critical' habitat depends on what is there as well as the habitat weighting parameters).

3 ECOLOGY SUB-MODEL FOR HIGH (FLOOD) FLOWS

Originally, the generalised approach would have been to develop a suite of riparian obligate indicators that would represent the geographical extent of South Africa and also have determinable links to river type with associated flow requirements. It was envisioned that the RDRM would be able to spatially query the riparian indicator distribution data and assign species specific flow rules to applicable river types. The underlying tenet was that these species specific rules would relate flood requirements to generic channel characteristics that could be defined by the profile of the channel, either directly or indirectly. The level of variability within a species would have been high however due to channel and geomorphic differences and to tease out such relationships would have meant that the sample size for each representative species would have been small. Rather than focus on species themselves, it was decided to focus on the actual flood requirements determined at each comprehensive Reserve site, irrespective of the species or indicators that determined such requirements and relate these to generic channel characteristics.

3.1 OBJECTIVES

Several intermediate and comprehensive-level reserve determination studies have been conducted within South Africa. These studies provide the opportunity to utilise detailed data that relate riparian species to their flow requirements as well as to channel characteristics. Utilizing as many of these sites as possible, the objective was to:

- Relate the flooding requirements that were determined at existing EWR sites to respective channel/flow characteristics.
- Relate flooding requirements as determined by riparian indicators to river type/geomorphic zone.
- Generalise any apparent relationships between flooding requirements and channel/flow characteristics in order to facilitate integration into the RDRM.
- Develop the flood component sub-model based on the quantification of such relationships.
- Undertake the required testing of the flood sub-model using existing detailed data from intermediate/comprehensive reserves already completed.
- Compile a user manual for the flood sub-model of the RDRM.

3.2 APPROACH

3.2.1 Site and Flow Characteristics

As many sites as possible were selected for inclusion in analyses but preference was given to intermediate Reserve determination sites. For each site the following was recorded:

- Level II ecoregion
- Geomorphic zone
- Altitude
- Bankfull discharge (this was determined from site profiles (see accompanying Excel spreadsheet), but indicator species were used in conjunction with the process)
- Discharge at the 50th percentile in the wettest month (PD FDC)
- Discharge at the 10th percentile in the wettest month (PD FDC)
- Discharge at the 1st percentile in the wettest month (PD FDC)
- Discharge required to activate the lowest occurring vegetation (this was determined from surveyed indicator vegetation on hydraulically rated profiles for each site)
- A measure of stream permanency (derived from the PD FDC)

3.2.2 Flooding Requirements

At each site flooding requirements were determined as part of the Reserve determination using riparian vegetation as indicators of floods required, but also incorporating the geomorphological requirements (which most frequently coincide with vegetation requirements). These flooding requirements were expressed as both frequency and duration of events, where events are defined by both peak discharge and average discharge, and frequency is defined as number of events per year. Where flood events occur less frequently than annually, frequency is expressed as an average return period. Duration was expressed as the number of days for which each respective event would last.

3.2.3 Relationships between Flooding Requirements and Channel/flow Characteristics

Relationships between flooding requirements and channel / flow characteristics were explored and generalised using simple curve fitting procedures. The following relationships were explored:

- Bankfull flow (a channel characteristic) with flooding frequency
- Discharge (PD) at the 1st percentile (a channel/flow characteristic) with flooding frequency
- Discharge (PD) at the 10th percentile (a channel/flow characteristic) with flooding frequency
- Discharge (PD) at the 50th percentile (a channel/flow characteristic) with flooding frequency
- Discharge (PD) required to activate marginal zone vegetation with flooding frequency

Stratification by geomorphic zone and stream permanency was additionally explored within each potential relationship to determine if this would improve relations.

3.3 RESULTS

3.3.1 Site and Flow Characteristics

General and geomorphic characteristics of sites utilized in analyses are shown in Table 3.1, while flow characteristics associated with each site are shown in Table 3.2.

Table 3.1 General and geomorphic characteristics of sites utilized in analyses

Project	EWR site name	River	Decimal deg S	Decimal deg E	EcoRegion (Level II)	Geomorphic Zone	Altitude (m)	Quat
Gouritz	Duivenhoks_EWR1	Duivenhoks	S34.25167	E20.99194	22.02	Lower Foothills	15	H80E
Gouritz	Gouko_EWR2	Gouko	S34.09324	E21.29300	22.02	Lower Foothills	87	H90C
Gouritz	Touws_EWR3	Touws	S33.72707	E21.16507	19.07	Lower Foothills	271	J12M
Gouritz	Gamka_EWR4	Gamka	S33.36472	E21.63051	19.09	Lower Foothills	375	J25A
Gouritz	Buffels_EWR5	Buffels	S33.38452	E20.94169	19.09	Lower Foothills	499	J11H
Gouritz	Gouritz_EWR6	Gouritz	S33.90982	E21.65233	19.08	Lower Foothills	121	J40B
Gouritz	Doring_EWR7	Doring	S33.79137	E20.92699	19.07	Lower Foothills	370	J12L
Gouritz	Keurbooms_EWR8	Keurbooms	S33.88955	E23.24392	20.02	Upper Foothills	161	K60C
Gouritz	Olifants_EWR9	Olifants	S33.43813	E23.20587	19.01	Lower Foothills	621	J31D
Gouritz	Kammanassie_EWR10	Kammanassie	S33.73286	E22.69740	19.01	Lower Foothills	445	J34C
Black Umfolozi	B Umfol_EWR	Black Umfolozi	S28 4.4543	E31 33.1886	14.04	Lower Foothills	232	W22F
Crocodile East	Valyspruit EWR 1_pool	Crocodile	S25 29.647	E30 08.656	9.02	Upper Foothills	1852	X21A
Crocodile East	Valyspruit EWR 1_riffle	Crocodile	S25 29.647	E30 08.656	9.02	Upper Foothills	1852	X21A
Crocodile East	Goedenhoop EWR 2	Crocodile	S25 24.555	E30 18.955	9.04	Upper Foothills	1207	X21B
Crocodile East	Poplar Creek EWR 3	Crocodile	S25 27.127	E30 40.865	10.02	Lower Foothills	834	X21E
Crocodile East	KaNyamazane EWR 4	Crocodile	S25 30.146	E31 10.919	4.04	Lower Foothills	472	X22K
Crocodile East	Malelane EWR 5	Crocodile	S25 28.972	E31 30.464	3.07	Lower Foothills	286	X24D
Crocodile East	Nkongoma EWR 6	Crocodile	S25 23.430	E31 58.467	12.01	Lower Foothills	135	X24H
Crocodile East	Honeybird EWR 7	Kaap	S25 38.968	E31 14.572	4.04	Upper Foothills	470	X23H
Sabie Sand	UpperSabie EWR1	Sabie	S25 04.424	E30 50.924	4.04	Upper Foothills	862	X31B
Sabie Sand	Sabie_Aan de Vliet EWR2	Sabie	S25 01.675	E31 03.099	4.04	Lower Foothills	463	X31D
Sabie Sand	Kidney EWR3	Sabie	S24 59.256	E31 17.572	3.07	Lower Foothills	369	X31K
Sabie Sand	MacMac EWR4	MacMac	S25 00.800	E31 00.243	4.04	Upper Foothills	582	X31C
Sabie Sand	Marite EWR5	Marite	S25 01.077	E31 07.997	4.04	Upper Foothills	457	X31G
Sabie Sand	Mutlumuvi EWR6	Mutlumuvi	S24 45.352	E31 07.923	3.05	Upper Foothills	503	X32F
Sabie Sand	Tlulandziteka EWR7	Sand	S24 40.829	E31 05.188	3.07	Lower Foothills	543	X32C
Sabie Sand	Sand EWR8	Sand	S24 58.045	E31 37.641	3.07	Lower Foothills	250	X32J
Mokolo	Vaalwater EWR 1a.2	Mokolo	S24 17.362	E28 05.544	6.02	Lower Foothills	1141	A42C
Mokolo	Tobacco EWR 1b	Mokolo	S24 10.697	E27 58.661	6.02	Lower Foothills	1043	A42E
Mokolo	Ka'ingo EWR 2	Mokolo	S24 03.897	E27 47.230	6.02	Lower Foothills	943	A42F

Project	EWR site name	River	Decimal deg S	Decimal deg E	EcoRegion (Level II)	Geomorphic Zone	Altitude (m)	Quat
Mokolo	Gorge EWR 3	Mokolo	S23 58.080	E27 43.614	6.01	Upper Foothills	871	A42G
Mokolo	Malalatau EWR 4	Mokolo	S23 46.272	E27 45.315	6.01	Lowland	842	A42G
Mvoti	Mv_I_EWR 1	Heynsspruit	S29 7.8324	E30 38.4012	16.02	Lower Foothills	929	U40B
Mvoti	Mv_I_EWR 2	Mvoti	S29 15.8388	E31 2.1078	17.03	Lower Foothills	203	U40H
Mvoti	Mg_I_EWR 2	Mgeni	S29 27.7104	E30 17.8992	16.03	Upper Foothills	725	U20E
Mvoti	Mg_I_EWR 5	Mgeni	S29 38.7126	E30 44.7336	17.03	Upper Foothills	177	U20L
Mvoti	Mk_I_EWR1a	Mkomazi	S29 38.7126	E30 44.7336	16.03	Lower Foothills	916	U20F
Mvoti	Mk_I_EWR1b	Mkomazi	S29 44.6028	E29 54.6990	16.03	Lower Foothills	916	U20F
Mvoti	Mk_I_EWR2	Mkomazi	S29 55.26	E30 5.0688	16.02	Upper Foothills	537	U20J
Mvoti	Mk_I_EWR3	Mkomazi	S30 7.9200	E30 39.747	17.01	Lower Foothills	50	U10M
Mvoti	Mg_R_EWR1	Mgeni	S29 30.7500	E30 5.6502	16.01	Lower Foothills	1081	U20A
Mvoti	Mg_R_EWR3	Karkloof	S29 26.4060	E30 18.1968	16.03	Upper Foothills	738	U20E
Mvoti	Lo_R_EWR1	Lovu	S30 5.9982	E30 44.1618	17.01	Lower Foothills	44	U70D
Mvoti	Mt_R_EWR1	Umtamvuna	S30 51.3648	E30 4.3608	17.01	Lower Foothills	277	T40E
Orange	Boegoeberg EFR 2	Orange	S29 0.3276	E22 9.7350	26.05	Lowland	871	D73C
Orange	Augrabies EFR 3	Orange	S28 25.7202	E19 59.898	28.01	Lowland	425	D81B
Orange	Vioolsdrif EFR 4	Orange	S28 45.315	E17 43.0176	28.01	Lowland	167	D82F
Orange	Upper Caledon EFR C5	Caledon	S28 39.0468	E28 23.25	15.03	Lower Foothills	1640	D21A
Orange	Lower Caledon EFR C6	Caledon	S30 27.1398	E26 16.2528	26.03	Lowland	1270	D24J
Orange	Lower Kraai EFR K7a	Kraai	S30 49.8333	E26 55.2333	26.03	Lowland	1327	D31M
Upper Vaal	Vaal-Uitkoms EWR1	Vaal	S26 52.368	E29 36.830	11.05	Lowland	1570	C11J
Upper Vaal	Vaal-Grootdraai EWR2	Vaal	S26 55.266	E29 16.758	11.03	Lowland	1537	C11L
Upper Vaal	Vaal-Gladdedrift EWR3	Vaal	S26 59.452	E28 43.783	11.03	Lowland	1487	C12H
Upper Vaal	Vaal-Deneys EWR4	Vaal	S26 50.557	E28 06.738	11.03	Lower Foothills	1445	C22F
Upper Vaal	Vaal-Scandinavia EWR5	Vaal	S26 55.946	E27 00.820	11.08	Lowland	1309	C23L
Upper Vaal	Klip EWR6	Klip	S27 21.700	E29 29.102	11.06	Lower Foothills	1593	C13D
Upper Vaal	Upper Wilge EWR 7	Klip			11.03	Lowland	1692	C81A
Upper Vaal	Wilge-Bavaria EWR8	Wilge	S27 48.010	E28 46.067	11.03	Lowland	1573	C82C
Upper Vaal	SuikerUS EWR 9	Suikerbosrant	S26 38.802	E28 22.918	11.01	Lower Foothills	1509	C21C
Upper Vaal	SuikerDS EWR10	Suikerbosrant	S26 40.882	E28 10.079	11.01	Lowland	1453	C21G
Upper Vaal	Blesbokspruit EWR11	Blesbokspruit	S26 28.735	E28 25.493	11.03	Lower Foothills	1528	C21F

Table 3.2 Flow characteristics utilized in analyses at selected sites

EWR site name	River	Bankfull Discharge (Peak)	PD Discharge @ 50th Percentile-wettest month	PD Discharge @ 10th Percentile-wettest month	PD Discharge @ 1st Percentile-wettest month	Peak discharge @ lowest vegetation	Stream Permanency (%)
Duivenhoks_EWR1	Duivenhoks	80	2.927	5.972	25.430	2.700	100
Gouko_EWR2	Gouko	80.7	1.225	4.699	11.547	0.010	75
Touws_EWR3	Touws	247	0.083	1.615	10.712	6.000	53
Gamka_EWR4	Gamka	213	0.184	13.483	79.710	0.002	100
Buffels_EWR5	Buffels	267	0.102	0.485	3.531	1.600	75
Gouritz_EWR6	Gouritz	610	1.472	39.575	295.181	0.600	100
Doring_EWR7	Doring	71	0.011	0.088	0.186	0.002	74
Keurbooms_EWR8	Keurbooms	128	1.157	2.958	5.522	1.300	100
Olifants_EWR9	Olifants	43.3	0.018	2.776	10.293	0.001	71
Kammanassie_EWR10	Kammanassie	13.6	0.255	1.792	31.714	0.010	57
B Umfol_EWR	Black Umfolozi	243	1.785	4.010	12.100	0.050	100
Valyspruit EWR 1_pool	Crocodile	10.8	0.674	2.399	5.527	0.150	100
Valyspruit EWR 1_riffle	Crocodile	9.9	0.674	2.399	5.527	0.210	100
Goedenhoop EWR 2	Crocodile	42.5	3.255	9.828	26.235	0.035	100
Poplar Creek EWR 3	Crocodile	205	3.764	22.261	64.983	0.361	100
KaNyamazane EWR 4	Crocodile	595	22.140	108.351	259.620	3.330	100
Malelane EWR 5	Crocodile	750	27.132	143.498	373.627	0.183	100
Nkongoma EWR 6	Crocodile	1100	23.115	160.106	408.825	0.078	100
Honeybird EWR 7	Kaap	255	3.805	21.355	38.913	0.017	80
UpperSabie EWR1	Sabie	75	4.781	16.962	34.284	0.500	100
Sabie_Aan de Vliet EWR2	Sabie	330	8.829	33.896	63.971	0.450	100
Kidney EWR3	Sabie	446	13.612	66.184	133.743	0.050	100
MacMac EWR4	MacMac	100	2.532	9.308	16.265	2.110	100
Marite EWR5	Marite	180	3.410	22.110	54.912	0.200	100
Mutlumuvi EWR6	Mutlumuvi	282	1.209	11.133	20.039	0.010	100
Tlulandziteka EWR7	Sand	89	0.342	6.184	11.324	0.004	100
Sand EWR8	Sand	377	2.200	36.274	116.380	0.420	100
Vaalwater EWR 1a.2	Mokolo	102	1.575	6.531	6.779	0.170	81
Tobacco EWR 1b	Mokolo	53.67	1.922	20.412	27.079	1.500	81
Ka'ingo EWR 2	Mokolo	47.03	2.940	75.493	97.751	0.640	71

EWR site name	River	Bankfull Discharge (Peak)	PD Discharge @ 50th Percentile-wettest month	PD Discharge @ 10th Percentile-wettest month	PD Discharge @ 1st Percentile-wettest month	Peak discharge @ lowest vegetation	Stream Permanency (%)
Gorge EWR 3	Mokolo	65	0.763	31.362	67.974	0.140	91
Malalatau EWR 4	Mokolo	320	0.763	31.362	67.974	0.100	90
Mv_I_EWR 1	Heynsspruit	36	0.325	1.154	5.429	0.002	100
Mv_I_EWR 2	Mvoti	150	7.042	25.753	76.703	0.450	100
Mg_I_EWR 2	Mgeni	115	4.833	19.116	35.387	0.070	100
Mg_I_EWR 5	Mgeni	222	8.443	39.259	89.300	0.300	100
Mk_I_EWR1a	Mkomazi	430	36.458	75.765	143.567	4.800	100
Mk_I_EWR1b	Mkomazi	650	36.458	75.765	143.567	1.700	100
Mk_I_EWR2	Mkomazi	1134	45.650	100.638	186.746	2.960	100
Mk_I_EWR3	Mkomazi	1130	51.157	120.841	220.546	0.200	100
Mg_R_EWR1	Mgeni	21	3.267	8.371	13.758	0.930	99
Mg_R_EWR3	Karkloof	20	2.899	7.295	12.504	0.890	98
Lo_R_EWR1	Lovu	110	2.371	7.986	35.756	0.220	100
Mt_R_EWR1	Umtamvuna	240	0.000	0.000	0.000	0.080	0
Boegoeberg EFR 2	Orange	2150	0.000	0.000	0.000	31.000	100
Augrabies EFR 3	Orange	2578	40.648	1398.860	2574.620	21.000	100
Vioolsdrif EFR 4	Orange	1695	29.995	1366.700	2364.000	23.000	100
Upper Caledon EFR C5	Caledon	70	0.000	0.000	0.000	0.200	0
Lower Caledon EFR C6	Caledon	1585	44.889	190.028	673.925	12.500	89
Lower Kraai EFR K7a	Kraai	1040	22.961	125.396	304.182	10.630	82
Vaal-Uitkoms EWR1	Vaal	710	8.505	57.257	236.693	0.420	100
Vaal-Grootdraai EWR2	Vaal	164	1.499	52.806	368.084	0.200	95
Vaal-Gladdedrift EWR3	Vaal	122	14.150	152.472	606.269	0.900	100
Vaal-Deneys EWR4	Vaal	950	14.912	245.143	1156.829	0.900	100
Vaal-Scandinavia EWR5	Vaal	1440	24.728	298.833	1304.154	2.950	100
Klip EWR6	Klip	117	2.687	23.924	54.285	0.150	100
Upper Wilge EWR 7	Klip	11	0.000	0.000	0.000	0.150	0
Wilge-Bavaria EWR8	Wilge	340	16.977	71.893	202.763	0.680	100
SuikerUS EWR 9	Suikerbosrant	60	0.713	4.771	19.230	0.130	100
SuikerDS EWR10	Suikerbosrant	167	4.285	16.889	56.746	0.350	100
Blesbokspruit EWR11	Blesbokspruit	30.5	3.429	7.789	21.059	0.360	100

3.3.2 Flooding Requirements

The flooding requirements used at each site are shown in Tables 3.3, 3.4 and 3.5 expressed as discharge (peak and average) and duration (days) of flood events respectively.

Table 3.3 Flood requirements expressed as discharge (daily peak as m^3/s) per flood frequency class per site.

EWR site name	Frequency (per year)								
	6	5	4	3	2	1	1:2	1:3	1:5
Touws_EWR3					4	10	50	90	120
Gamka_EWR4		1.7	5		20			50	120
Buffels_EWR5				10	3			30	
Gouritz_EWR6		16			30	60		350	700
Doring_EWR7			0.4		0.8	2.1			
Keurbooms_EWR8			4.5			20			90
Olifants_EWR9						2.8		15	
Kammanassie_EWR10			0.7		3	7.5			
Duivenhoks_EWR1			3		16	28			
Gouko_EWR2			2.8		6.8	10.8			
B Umfol_EWR	3				9	65			150
Valyspruit EWR 1_pool					2	5		10	
Valyspruit EWR 1_riffle					2	5		10	
Goedenhoop EWR 2			5			10	25		35
Poplar Creek EWR 3			13		32	60	90		
KaNyamazane EWR 4			40			110	220	330	
Malelane EWR 5			20		50	100		370	
Nkongoma EWR 6			30		100	160	350		1000
Honeybird EWR 7			8			12	80	130	
UpperSabie EWR1			7			20	55		70
Sabie_Aan de Vliet EWR2			12			25	55		70
Kidney EWR3			30			55	100	150	
MacMac EWR4			5			15	35	70	
Marite EWR5			6			18	42	80	250
Mutlumuvi EWR6			2.5			12	30	50	190
Tlulandziteka EWR7			2.5			9		68	
Sand EWR8			7			65		150	
Vaalwater EWR 1a.2			5			11		45	
Tobacco EWR 1b			8			19	40	55	
Ka'ingo EWR 2				12		20	35	40	
Gorge EWR 3			5			16		30	
Malalatau EWR 4			8			25	50	70	
Mv_I_EWR 1			2					25	
Mv_I_EWR 2		20				40	60		130
Mg_I_EWR 2			10			30	50		
Mg_I_EWR 5			15		30	50	100		200
Mk_I_EWR1a				50	80	120			300
Mk_I_EWR1b				50	80	120			300
Mk_I_EWR2				60	100	200		350	
Mk_I_EWR3			60		100	200		350	
Mg_R_EWR1	2				10	20			

EWR site name	**Frequency (per year)**								
	6	**5**	**4**	**3**	**2**	**1**	**1:2**	**1:3**	**1:5**
Mg_R_EWR3	4			7.5		10			
Lo_R_EWR1			10		25	35		90	
Mt_R_EWR1	8		25			40	50	150	
Boegoeberg EFR 2				200		400		1000	2000
Augrabies EFR 3				200		450		780	1200
Vioolsdrif EFR 4			70	170		340	600	1000	
Upper Caledon EFR C5			10		5	20		45	
Lower Caledon EFR C6			70		130	400			650
Lower Kraai EFR K7a			60		14	125		400	650
Vaal-Uitkoms EWR1			10		35	120		340	420
Vaal-Grootdraai EWR2	4		10			50	100		
Vaal-Gladdedrift EWR3			20			80	130		
Vaal-Deneys EWR4			30			96	200		
Vaal-Scandinavia EWR5			100			260	570	800	
Klip EWR6			7			15	50	90	
Upper Wilge EWR 7			3		9	11			
Wilge-Bavaria EWR8			12		30	90	150		
SuikerUS EWR 9			2			6	20	40	
SuikerDS EWR10				6		12	40	70	
Blesbokspruit EWR11				6	10	25			

Table 3.4 Flood requirements expressed as discharge (daily average as m^3/s) per flood frequency class per site.

EWR site name	Frequency (per year)								
	6	**5**	**4**	**3**	**2**	**1**	**1:2**	**1:3**	**1:5**
Touws_EWR3					3.6	8.3	40	50	82
Gamka_EWR4		1.6	4.4		15.7			36.6	81.8
Buffels_EWR5				8.3				23	
Gouritz_EWR6		12.8			23	43.2		219	415
Doring_EWR7									
Keurbooms_EWR8			4			15			50
Olifants_EWR9						2.5		12	
Kammanassie_EWR10									
Duivenhoks_EWR1									
Gouko_EWR2									
B Umfol_EWR	2.7				7.5	46.5			100.5
Valyspruit EWR 1_pool					1	3		8.3	
Valyspruit EWR 1_riffle					1	3		8.3	
Goedenhoop EWR 2			3			8	18		25
Poplar Creek EWR 3			8		15	30	80		
KaNyamazane EWR 4			32			82	180	280	
Malelane EWR 5			18		35	85		330	
Nkongoma EWR 6			25		75	145	280		800
Honeybird EWR 7			5.5			9	34	82	
UpperSabie EWR1			5.5			12.5	40		55
Sabie_Aan de Vliet EWR2			10			16.5	40		60
Kidney EWR3			17			48	85	120	

EWR site name	Frequency (per year)								
	6	**5**	**4**	**3**	**2**	**1**	**1:2**	**1:3**	**1:5**
MacMac EWR4			3.8			8.2	28	62	
Marite EWR5			4.5			10	32	55	180
Mutlumuvi EWR6			1.8			10	20	43	125
Tlulandziteka EWR7			1.8			5		55	
Sand EWR8			4.5			38		132	
Vaalwater EWR 1a.2			2.8			8.2		38	
Tobacco EWR 1b			4.8			12	32	48	
Ka'ingo EWR 2				6		16	28	38	
Gorge EWR 3			2.8			12		28	
Malalatau EWR 4			5.8			19	42	65	
Mv_I_EWR 1			1.5					10	
Mv_I_EWR 2		12				30	40		100
Mg_I_EWR 2			6			20	50		
Mg_I_EWR 5			10		20	40	80		150
Mk_I_EWR1a				30	70	90			250
Mk_I_EWR1b				30	70	90			250
Mk_I_EWR2				40	75	150		260	
Mk_I_EWR3			45		75	150		260	
Mg_R_EWR1	1.2				6	15			
Mg_R_EWR3	2.5			5.5		9			
Lo_R_EWR1			2.5		10	25		50	
Mt_R_EWR1	6		18			32	50	150	
Boegoeberg EFR 2				150		350		850	2000
Augrabies EFR 3				150		350		680	1000
Vioolsdrif EFR 4			60	170		340	500	1000	
Upper Caledon EFR C5			5		2.5	10		35	
Lower Caledon EFR C6			50		110	200			500
Lower Kraai EFR K7a			35		10	110		300	520
Vaal-Uitkoms EWR1			5		15	50		200	380
Vaal-Grootdraai EWR2	2		6			11	70		
Vaal-Gladdedrift EWR3			15			40	100		
Vaal-Deneys EWR4			20			40	120		
Vaal-Scandinavia EWR5			40			180	400	680	
Klip EWR6			5			10	20	45	
Upper Wilge EWR 7			2		8	11			
Wilge-Bavaria EWR8			6		15	65	100		
SuikerUS EWR 9			1			3	8	28	
SuikerDS EWR10				5		8	20	58	
Blesbokspruit EWR11				4	8	17			

Table 3.5 Flood requirements expressed as duration (number of days) per flood frequency class per site.

EWR site name	Frequency (per year)								
	6	**5**	**4**	**3**	**2**	**1**	**1:2**	**1:3**	**1:5**
Touws_EWR3					6	3	3.5	5	6
Gamka_EWR4		6	6		4			5	7
Buffels_EWR5				5				7	

EWR site name	Frequency (per year)								
	6	**5**	**4**	**3**	**2**	**1**	**1:2**	**1:3**	**1:5**
Gouritz_EWR6		5			6	7		9	10
Doring_EWR7									
Keurbooms_EWR8			3			4			4
Olifants_EWR9						4		6	
Kammanassie_EWR10									
Duivenhoks_EWR1									
Gouko_EWR2									
B Umfol_EWR	4				5	8			10
Valyspruit EWR 1_pool					3	3		5	
Valyspruit EWR 1_riffle					3	3		5	
Goedenhoop EWR 2			3			4	5		6
Poplar Creek EWR 3			5		4	3	5		
KaNyamazane EWR 4			3			4	5	6	
Malelane EWR 5			5		3	3		6	
Nkongoma EWR 6			3		3	4	5		6
Honeybird EWR 7			3			3	4	5	
UpperSabie EWR1			3			3	4		5
Sabie_Aan de Vliet EWR2			3			3	4		5
Kidney EWR3			3			5	6	7	
MacMac EWR4			3			3	4	5	
Marite EWR5			3			3	4	5	6
Mutlumuvi EWR6			3			5	5	6	
Tlulandziteka EWR7			3			5		6	
Sand EWR8			3			5		6	
Vaalwater EWR 1a.2			2			3		5	
Tobacco EWR 1b			2			3	3	5	
Ka'ingo EWR 2				2		3	3	5	
Gorge EWR 3			2			3		5	
Malalatau EWR 4			3			4	4	5	
Mv_I_EWR 1			8					15	
Mv_I_EWR 2		7				10	12		14
Mg_I_EWR 2			10			12	12		
Mg_I_EWR 5			10		10	12	12		12
Mk_I_EWR1a				5	6	7			7
Mk_I_EWR1b				5	6	7			7
Mk_I_EWR2				6	7	7		8	
Mk_I_EWR3			6		7	8		8	
Mg_R_EWR1	2				4	6			
Mg_R_EWR3	3			4		6			
Lo_R_EWR1			3		4	6		8	
Mt_R_EWR1	3		4			6	7	8	
Boegoeberg EFR 2				6		8		12	12
Augrabies EFR 3				6		8		12	12
Vioolsdrif EFR 4			5	6		8	12	12	
Upper Caledon EFR C5			4		3	5		6	
Lower Caledon EFR C6			5		6	7			8
Lower Kraai EFR K7a			5		4	6		7	8
Vaal-Uitkoms EWR1			5		5	5		6	7
Vaal-Grootdraai EWR2	3		4			5	6		

EWR site name	Frequency (per year)								
	6	5	4	3	2	1	1:2	1:3	1:5
Vaal-Gladdedrift EWR3			3			4	5		
Vaal-Deneys EWR4			5			5	6		
Vaal-Scandinavia EWR5			5			5	6	7	
Klip EWR6			4			5	6	7	
Upper Wilge EWR 7			3		4	5			
Wilge-Bavaria EWR8			3		4	5	6		
SuikerUS EWR 9			3			5	6	7	
SuikerDS EWR10				3		5	6	7	
Blesbokspruit EWR11				3	5	6			

3.3.3 Relationships between Flooding Requirements and Channel/flow Characteristics

Bankfull Flow

Second or third order polynomial trend lines adequately describe the relationships (R^2 >= 0.83) between both intra-annual (Figure 3.1) and inter-annual (including annual; Figure 3.2) flood requirements and bankfull discharge respectively, except where 6 or 5 flood events are required per year (Figure 3.3). There were only 5 sites that had a flooding requirement which included 6 events per year and variability was high between even these 5 sites, and as such there was no clear relationship with bankfull discharge. Similarly, there were only 2 sites that had a flooding requirement which included 5 events per year so the relationship, while good, is likely artificial. Stratifying comparisons by geomorphic zone resulted in better relationships in only some instances (bold values in Table 3.6), but this was mostly not the case. Apparent improvements to R^2-values of 1 denote sites with low sample size, in some cases only 2 samples.

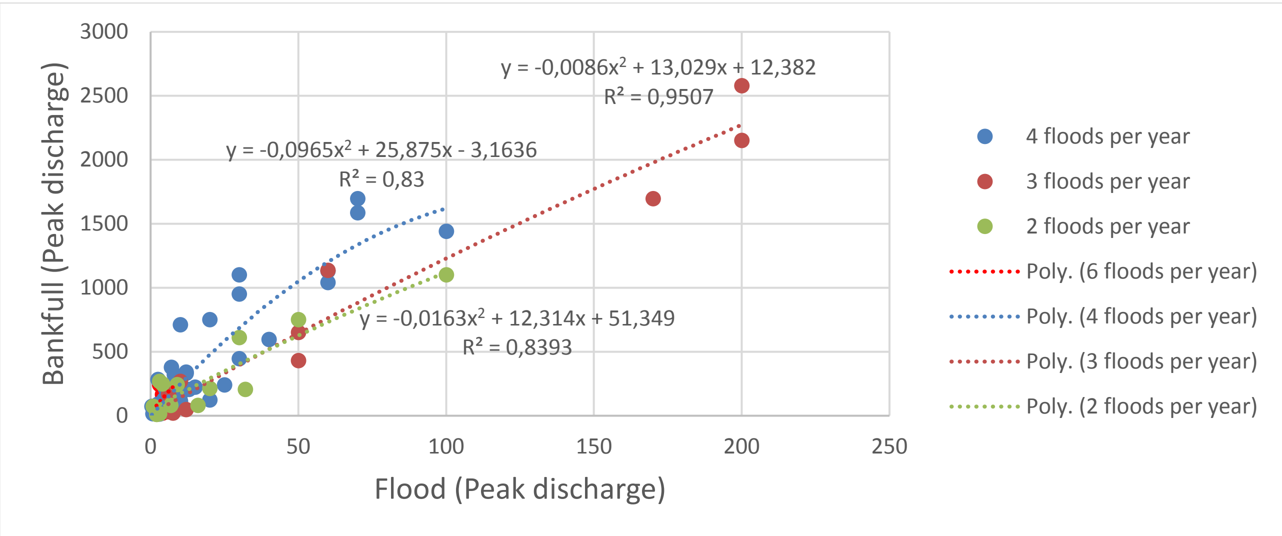

Figure 3.1 Relationship between bankfull discharge and intra-annual flood requirements (6 events shown in Figure 3.3).

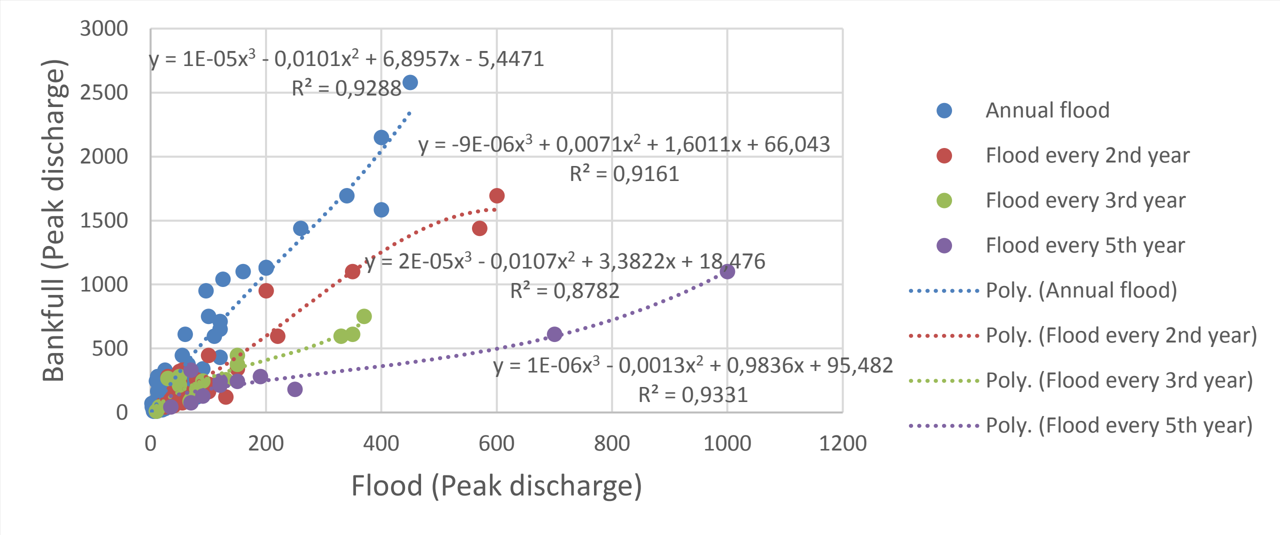

Figure 3.2 **Relationship between bankfull discharge and inter-annual flood requirements, including the annual flood.**

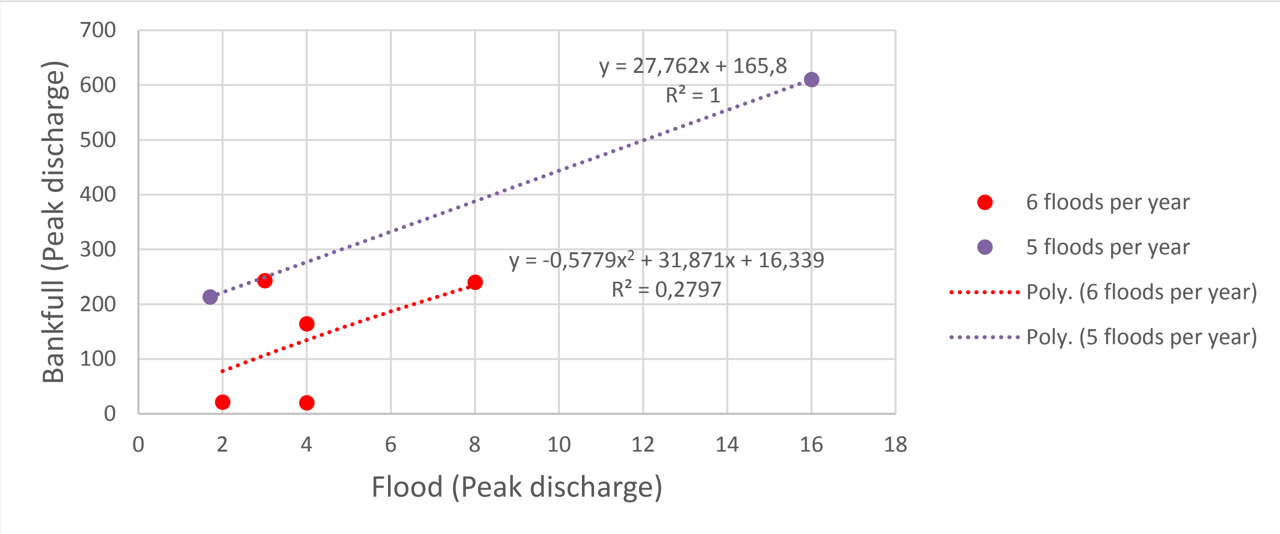

Figure 3.3 **Relationship between bankfull discharge and intra-annual flood requirements where 6 or 5 events are required per year.**

Table 3.6 **Best achievable R^2-values that describe the goodness-of-fit for relationships between bankfull discharge and flooding frequency, stratified by geomorphic zone as a comparison to all sites combined.**

Geomorphic zone	**Frequency (per year)**								
	6	**5**	**4**	**3**	**2**	**1**	**1:2**	**1:3**	**1:5**
All	0.280	1.000	0.830	0.951	0.839	0.929	0.916	0.878	0.933
Lower foothills	**0.384**	0.035	0.733	0.794	0.775	0.831	0.887	0.857	0.852
Upper foothills	n/a	n/a	0.059	1.000	1.000	0.913	0.234	**0.945**	0.677
Lowland River	n/a	n/a	0.812	**0.998**	0.823	0.929	**0.956**	0.789	0.560

Discharge (PD) at the 1st Percentile

Trend lines adequately describe the relationships between less frequent intra-annual flood requirements (2,3 or 4 day events) and PD discharge at 1st percentile, but less so for more frequent intra-annual flood requirements (5 and 6 day events; Figure 3.4). Second or third order polynomial trend lines adequately describe the relationships between inter-annual and annual flood requirements and PD discharge at the 1st percentile (Figure 3.5). In some cases, but not the majority, the relationship between flood requirements and PD discharge at the 1st percentile is better than described by bankfull discharge.

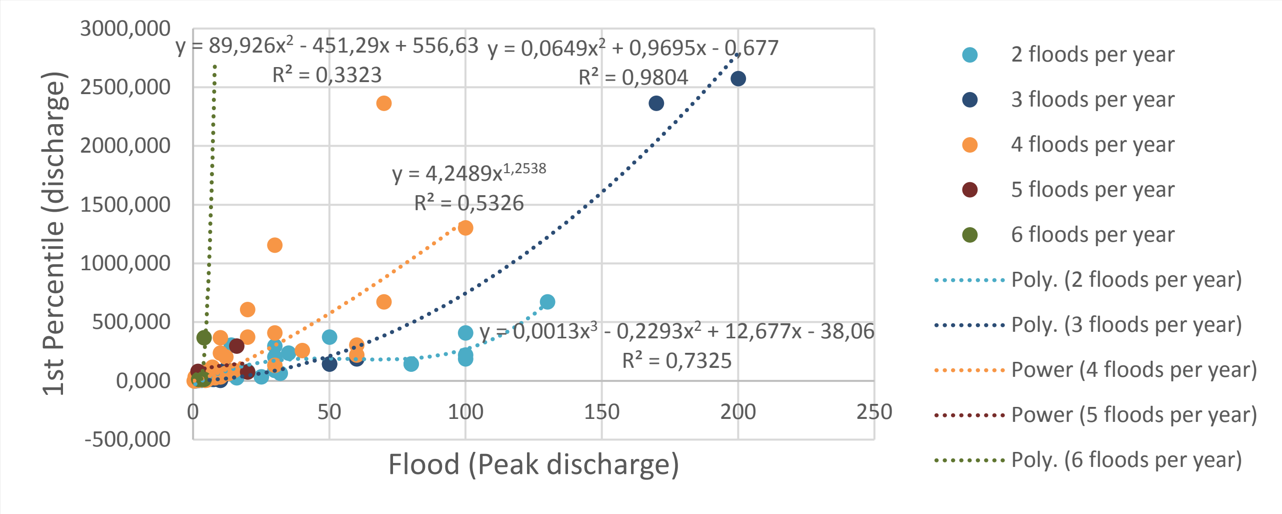

Figure 3.4 Relationship between PD discharge at the 1st percentile and intra-annual flood requirements.

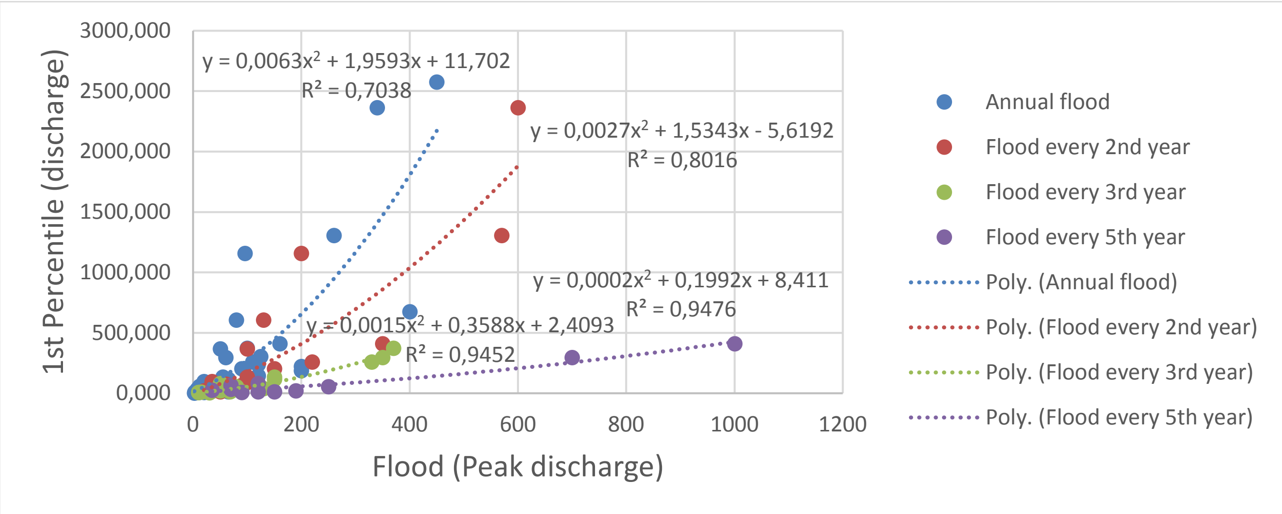

Figure 3.5 Relationship between PD discharge at the 1st percentile and inter-annual flood requirements, including the annual flood.

Discharge (PD) at the 10th Percentile

Trend lines adequately describe the relationships between less frequent intra-annual flood requirements (2,3 or 4 day events) and PD discharge at 10th percentile, but less so for more frequent intra-annual flood requirements (5 and 6 day events; Figure 3.6). Second or third order polynomial trend lines adequately describe the relationships between inter-annual and annual flood requirements and PD discharge at the 10th percentile (Figure 3.7), but least so for the annual flood. In some cases, but not the majority, the relationship between flood requirements and PD discharge at the 10th percentile is better than described by bankfull discharge.

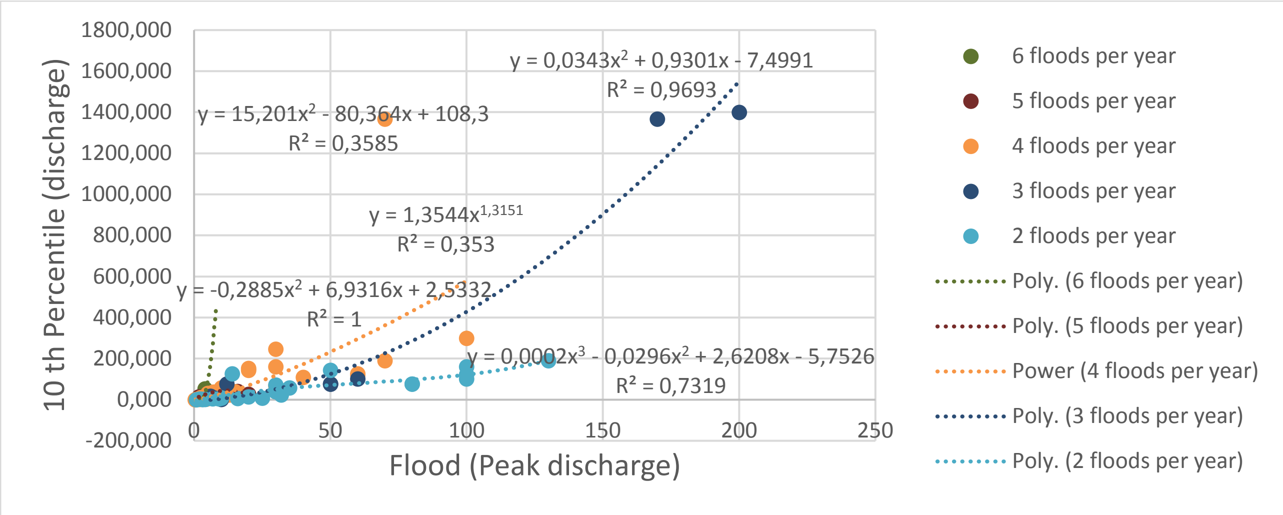

Figure 3.6 **Relationship between PD discharge at the 10th percentile and intra-annual flood requirements.**

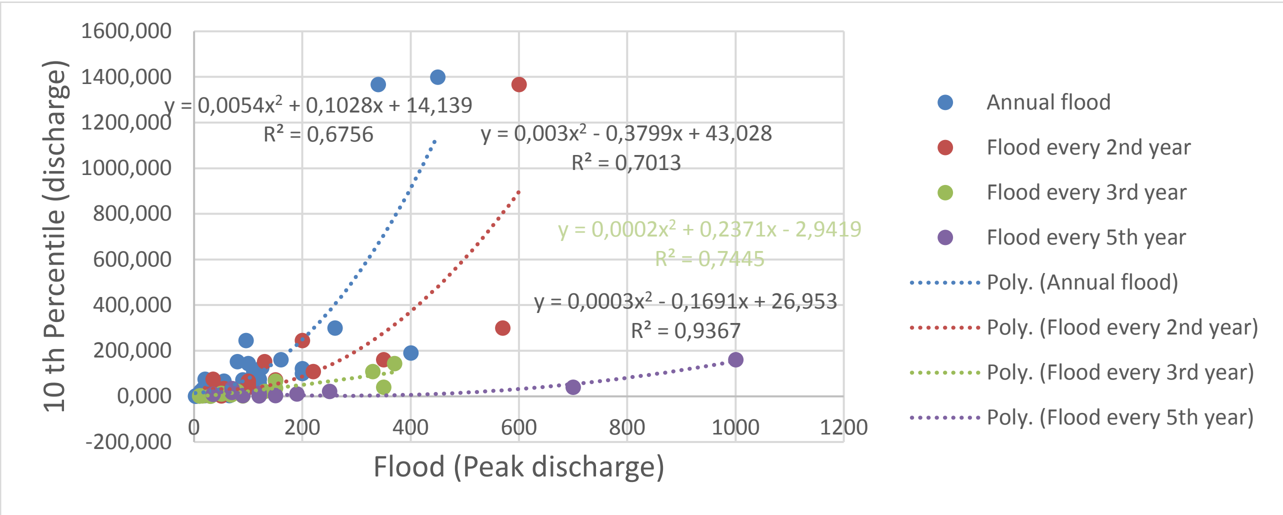

Figure 3.7 **Relationship between PD discharge at the 10th percentile and inter-annual flood requirements, including the annual flood.**

Discharge (PD) at the 50th Percentile

Trend lines adequately describe the relationships between intra-annual flood requirements (except for 6-day events) and PD discharge at the 50th percentile (Figure 3.8). Second or third order polynomial trend lines adequately describe the relationships between inter-annual and annual flood requirements and PD discharge at the 50th percentile (Figure 3.9), but least so for the 1 in 3 year flood. In some cases, but not the majority, the relationship between flood requirements and PD discharge at the 50th percentile is better than described by bankfull discharge.

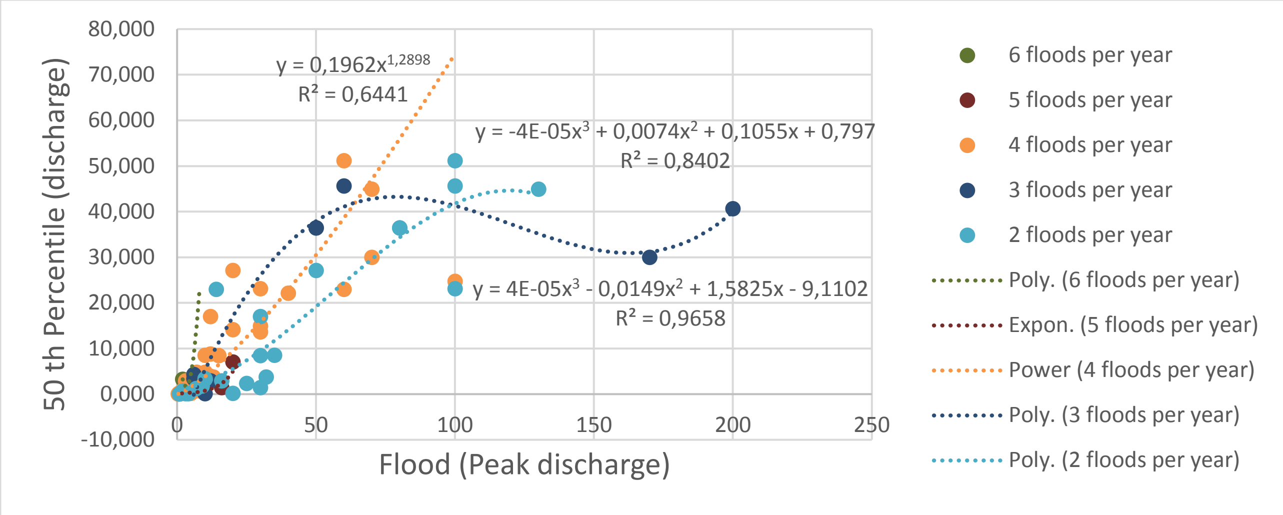

Figure 3.8 **Relationship between PD discharge at the 50th percentile and intra-annual flood requirements.**

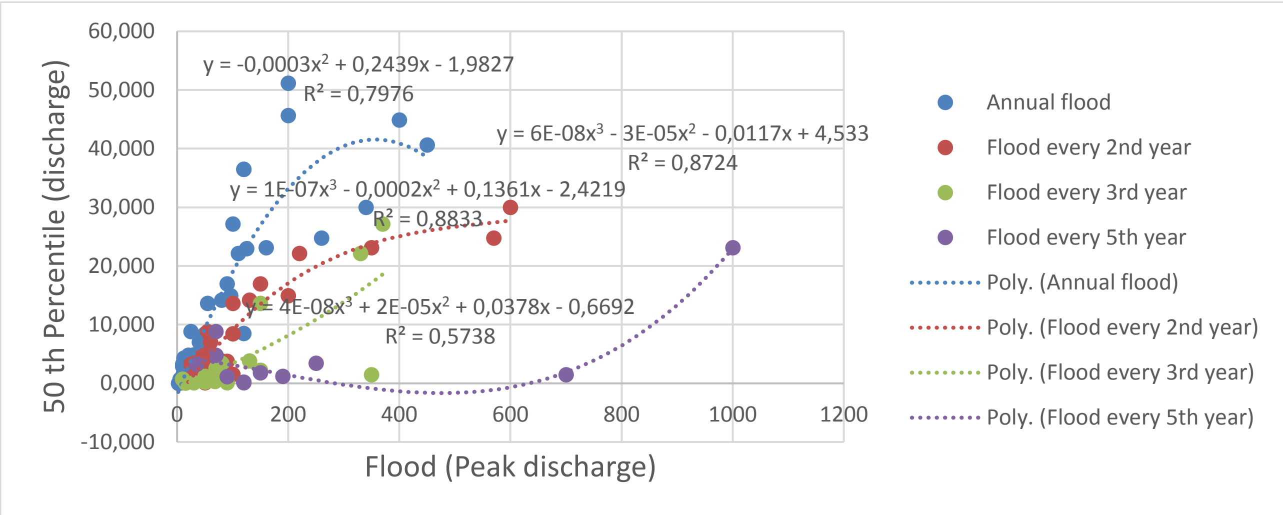

Figure 3.9 **Relationship between PD discharge at the 50th percentile and inter-annual flood requirements, including the annual flood.**

Discharge (PD) Required to Activate Marginal Zone Vegetation

Trend lines adequately describe the relationships between some intra-annual flood requirements and PD discharge required to activate marginal zone vegetation, but not others (Figure 3.10). A third order polynomial trend line adequately describes the relationships between the annual flood requirement and PD discharge required to activate marginal zone vegetation, but does not describe the relationship well for inter-annual floods (Figure 3.11). The relationship between flood requirements and PD discharge required to activate marginal zone vegetation is never better than described by bankfull discharge.

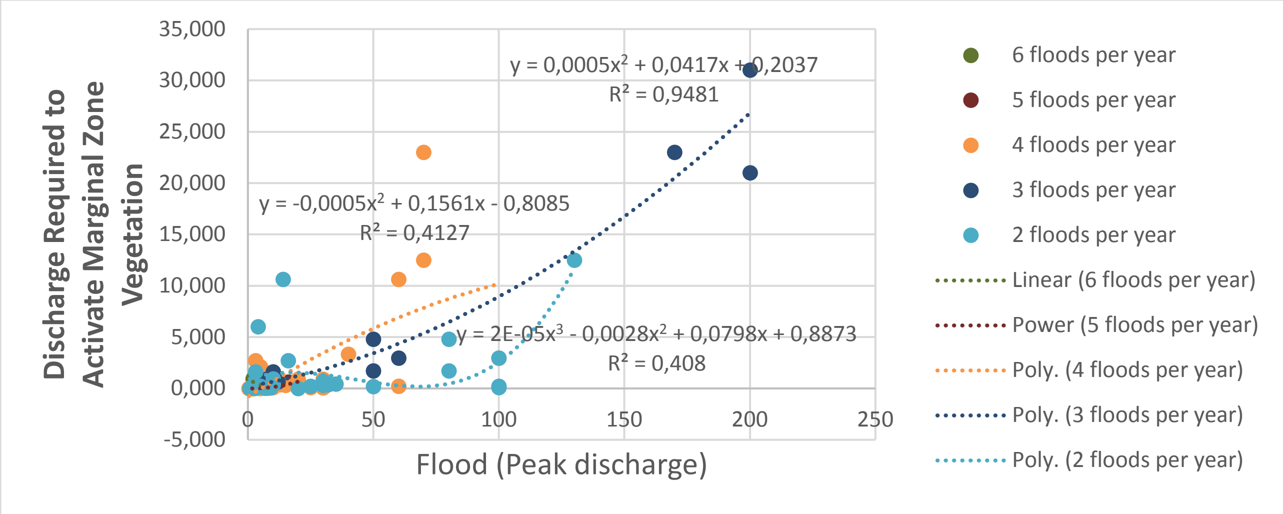

Figure 3.10 Relationship between PD discharge required to activate marginal zone vegetation and intra-annual flood requirements.

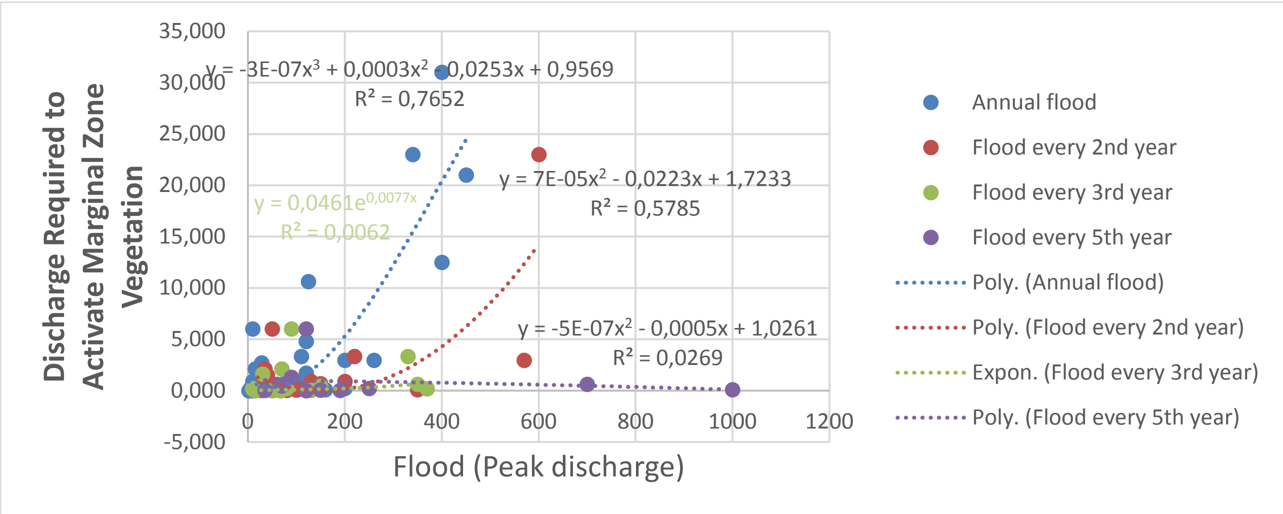

Figure 3.11 Relationship between PD discharge required to activate marginal zone vegetation and inter-annual flood requirements, including the annual flood

3.3.4 Analysis of Flood Requirements from Previous Reserve Studies

Between all 62 sites, an average of 3.8 flood classes was specified for flood requirements. The minimum number of flood classes ever required was 2 and the maximum was 5 (Table 3.7). The desktop model allows for the definition of 5 flood classes and data support that this is sufficient.

Table 3.7 The frequency with which the number of flood classes were assigned to sites as part of the flood requirement.

Number of flood classes that were specified in the flood requirement	Number of sites which had the requirement
2	2
3	18
4	30
5	12

3.3.5 Determination of Flood Frequency

An analysis of flood frequency showed that of the 62 sites the annual flood was determined as part of the requirement 95.2% of the time (Table 3.8). For the within-year floods, 4 events and 2 events were most often specified (71% and 45.2% of the time respectively). The inter-annual floods with a return period of 1 in every 2, 3 and 5 years were also specified in a high percentage of cases. Although the flood component in desktop model allows for user interface and hence the flexibility to determine both flood frequency and magnitude, these results were used the guide the desktop process in the absence of a specialist user, i.e. the desktop version caters for 4 class 1 floods, 2 class 2 floods, 1 class 3 flood, a class 4 flood every other year and a class 5 flood every 5 years.

Table 3.8 The proportion of sites (%) with specified flood frequency requirements.

Frequency (events per year)								
6	**5**	**4**	**3**	**2**	**1**	**1 every 2 years**	**1 every 3 years**	**1 every 5 years**
9.7	4.8	71.0	17.7	45.2	95.2	46.8	58.1	35.5

3.3.6 Relation of Flood Requirements to Bankfull

In order to use the data to guide the desktop model it was required to relate flooding requirements to characteristics of the channel that the desktop generates. The bankfull flow was selected since this represents the most flow possible in any desktop channel and can therefore be consistently determined within the model. Determination of bankfull discharge on the 62 real transects proved problematic at times however. Nevertheless good relationships were found to exist between envisioned bankfull and flood peak discharges of the various category floods (Figure 3.12 for within-year floods, and Figure 3.13 for inter-annual floods). These relationships were used to scale the desktop bankfull discharge in order to assign peak discharge values to the 5 flood classes.

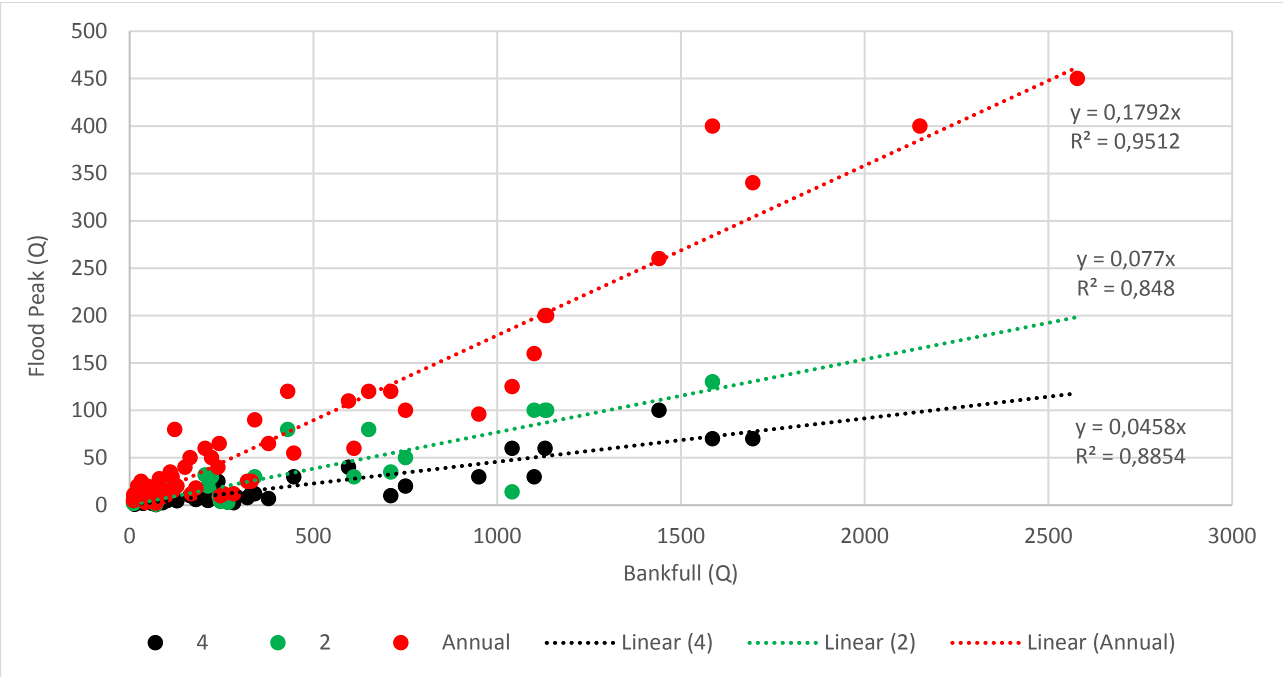

Figure 3.12 Relationship between bankfull discharge and flood peak discharge for within-year floods, including the annual event.

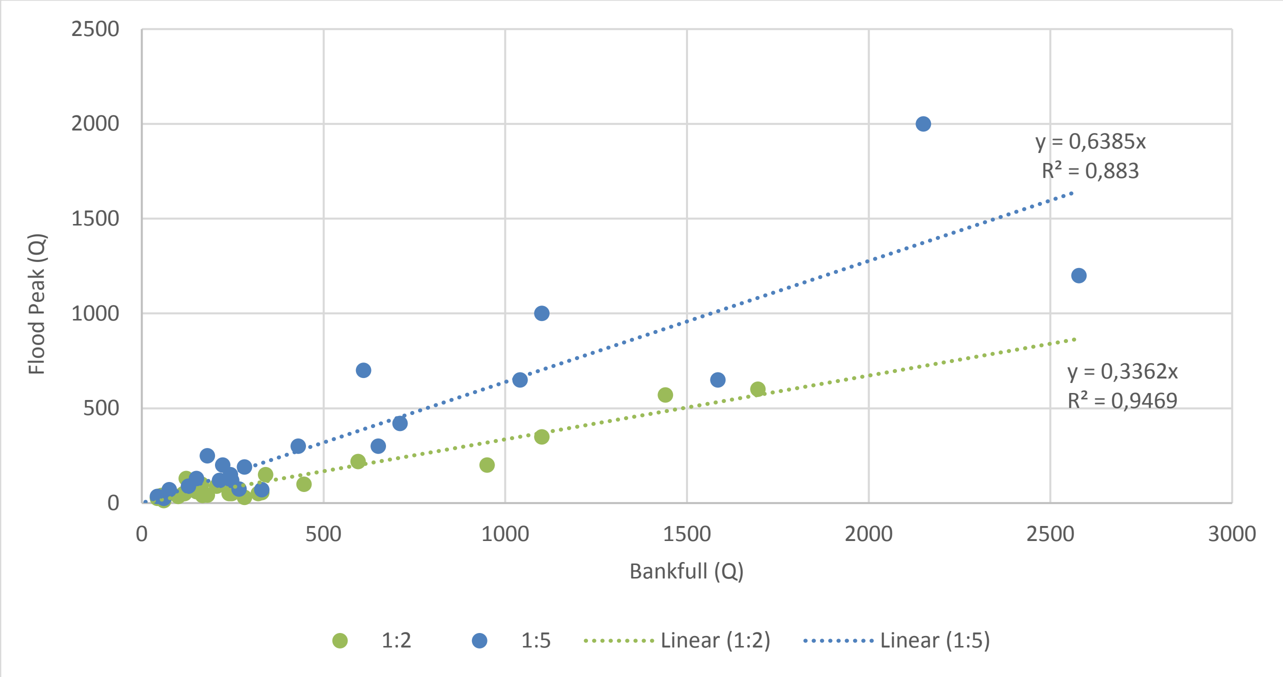

Figure 3.13 Relationship between bankfull discharge and flood peak discharge for inter-annual floods.

3.3.7 Relation of Flood Requirements to Maximum Base Flow

If the desktop model has flow data it can also consistently evaluate maximum base flow in the wet season for any channel that it generates. It was therefore decided to also explore any relationship of flood requirements with maximum wet season base flow. The discharge values for maximum wet season base flow were not available for all sites however and the sample size was reduced to 16 sites. There was nevertheless a good relationship between the maximum base flow and within-year floods, including the annual event (Figure 3.14). These relationships will also be used in the desktop model to define floods, i.e. if the maximum wet season base flow is known then class 1 floods (4 events per year) are 1.6 times greater, class 2 floods (2 events per year) are 3.2 times greater and the annual flood is 5.8 times maximum wet season base flow.

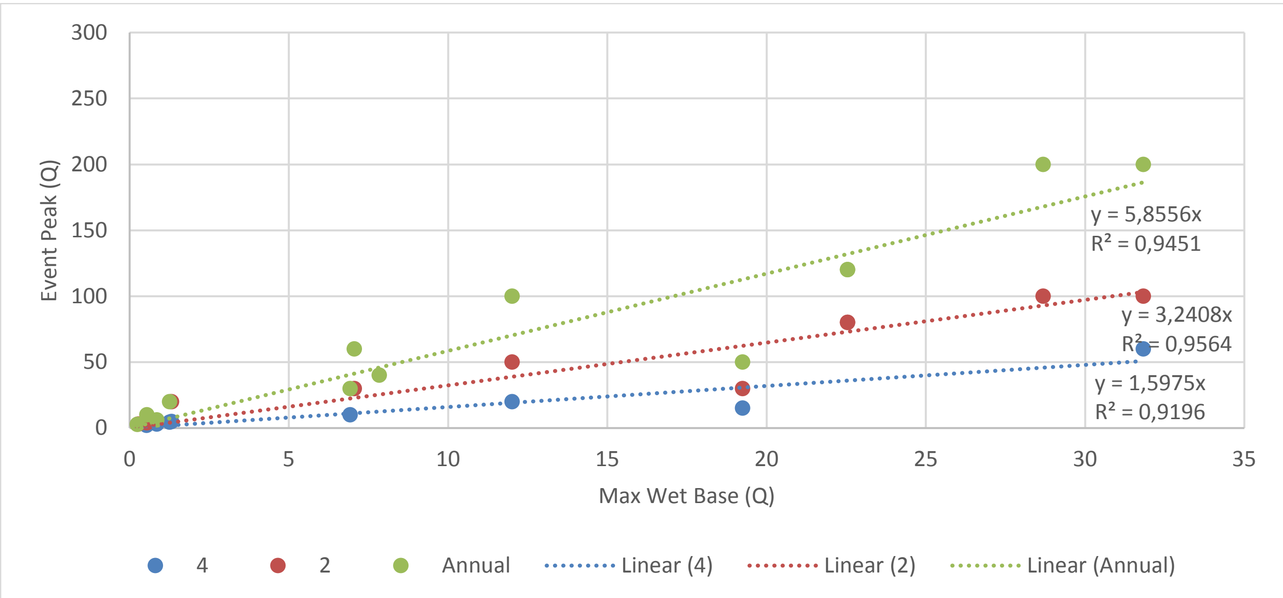

Figure 3.14 Relationship between maximum wet season base flow and flood peak discharge, for within-year floods, including the annual event.

3.4 SUMMARY

It is possible to adequately (taken as $R^2 > 0.8$) relate channel characteristics (such as bankfull discharge) and flow characteristics related to the channel (such as discharge at various percentiles according to exceedance values or marginal vegetation distribution) to the flood requirements as determined by riparian vegetation and to a lesser extent fluvial geomorphology (Table 3.9). Given the profile at a site these relationships should be able to adequately define the flood requirement, and as such have potential for use within the RDRM. Values in Table 3.9 which are highlighted in red, are greater than 0.8 and highlight a quantifiable relationship that may be used to determine flood requirements at the desktop level. Clearly there is at least one useful channel characteristic for each of the flood frequency classes besides the most frequent of 6 events per year. Overall the bankfull discharge most adequately described acceptable relationships for most flood frequency classes. In addition, once a flood frequency class has been quantified in terms of its discharge (according the best relationship derived), its duration may be derived from using the average duration stipulated for the flood requirement for that particular frequency class (Table 3.10).

Table 3.9 Best R^2 values that quantify the quality of relationships between channel / flow characteristics and flood requirements.

Channel / Flow Characteristic	Flood Frequency (events per year or return period)								
	6	5	4	3	2	1	1:2	1:3	1:5
Bankfull discharge	0.280	1.000	0.830	0.951	0.839	0.929	0.916	0.878	0.933
1st Percentile	0.332	0.164	0.733	0.980	0.733	0.704	0.802	0.945	0.948
10th Percentile	0.359	1.000	0.844	0.969	0.732	0.676	0.701	0.745	0.937
50th Percentile	0.552	0.947	0.815	0.966	0.840	0.798	0.883	0.574	0.872
Discharge to activate marginal vegetation	0.251	0.984	0.413	0.948	0.408	0.765	0.579	0.121	0.027

Table 3.10 Average duration (days) for various flood frequency classes.

	Flood Frequency (events per year or return period)								
	6	5	4	3	2	1	1:2	1:3	1:5
Average Event Duration (days)	3	4	4.08	4.64	4.87	5.28	5.95	6.92	8

4 DESIGN OF THE REFINED RDRM

The input requirements have been slightly simplified as detailed below:

- The use of the old Desktop Single Parameter inputs has been removed and the regional baseflow parameters incorporated into the 'Hydrology/Hydraulic parameter' input.
- The 'Hydrology/Hydraulic parameter' no longer uses the flood region to estimate the full channel width in the hydraulic sub-model, which will now become a parameter (obtained from examining Google Earth). The bankfull channel depth uses an approach based on regionalized parameters of classic channel hydraulic geometry equations (that relate width and depth to catchment area). This is considered to be a better long-term solution given the unreliability of the previous flood estimation methods. The hydraulic geometry relationships used to estimate channel depth from channel width are based on two equations:

  $Width = a*Qbank^{b}$
  $Depth = c*Qbank^{f}$

  Giving

  $Depth = ((Width / a)^{1/b})^{f} * c$

  The parameters a, b and f are fixed in the model but the user can change the value of the scale parameter (c) if additional information is available about the likely channel depth. The default value is 0.5 and the results are very sensitive to values that are very different to this (minimum value is 0.35 and maximum value is 0.65).

The 'Ecological parameter' input remains similar to the previous model, but direct methods of estimating most of the stress weights and shifts, as well as the flood parameters, are used and linked to an ecological database. This means that the use of the model is simpler as the majority (if not all) of these parameters will not need to be estimated by a user if they are applying the model without any specialist input (i.e. purely as a desktop application). It will continue to be possible for 'expert' users to modify the default parameters.

4.1 HYDROLOGY SUB-MODEL

The hydrology sub-model remains largely un-changed except that the calculation of the monthly high flows with different frequencies of exceedance has been removed as it is not required for the new Ecology sub-model for high flows.

4.2 HYDRAULICS SUB-MODEL

There were relatively few modifications to the hydraulics sub-model except in the following areas:

- The method for estimating channel depth has changed (see above).
- The channel bed profile (macro roughness) of the estimated channel cross-sectional shape for geomorphological regions 5 and 6 was changed to reduce the rather excessive variations in the bed profile that has been noted in the previous version of the model.
- The implication of the above change is that large channels will end up having smoother bed profiles and this should make the hydraulics sub-model a bit faster to complete (it was previously quite slow for large channels).
- The channel width parameter is now a user-estimated parameter (obtained from Google Earth or a suitable alternative).

- There are more direct links between the channel cross-section and estimated stage-discharge curve and the ecological sub-model for high flows. This change does not affect users but involved some code changes.
- A very specialized input has been added to the model to allow the definition of the different habitat types to be changed temporarily in any model run. This was mainly added as some ecologists required the 'Fast' definition to be increased from the default value of 0.3 m s^{-1}.

4.3 ECOLOGICAL SUB-MODEL (LOW FLOWS)

4.3.1 The stress-flow parameters and how they will be used in the RDRM

One of the key issues was that the basic principles of the rule base could be retained. Some additional rules were developed to provide improved links between the model algorithms and the ecological database. It was also decided that the links between the parameters and the ecological database will be made outside the RDRM through an additional program that will generate parameter estimates for all polygons of a national catchment area coverage. This coverage will then be interrogated by a user who is working at a specific location. The stress weights for those sites where fish species have been identified as being present in the ecological database will therefore be extracted from the underlying national catchment coverage. Under conditions where no fish are present (or important) the default stress weights become (FS:2, FI:1, FD:0) for the wet season and (FS:3; FI:1; FD:0) for the dry season.

A second rule refers to the stress at which the optimum habitats disappear. It was decided that, in the absence of fish requirements, this value should be 9 for the wet season and 5 for the dry season in all perennial rivers. In non-perennial systems these values would be reduced on the basis of the % time of zero flows, but the exact calculation of the reductions has not been determined yet. The discharge rate for setting the maximum stress value will be based on the deepest of the optimum fast habitats (i.e. those that have non-zero weights).

As noted above, the rules for estimating the initial stress values for each habitat type tend to ignore the fact that the intermediate and shallow habitats are quite small if there is a significant amount of fast deep habitat. The stress curves do not therefore reflect the changes that occur in FS and FI at quite low flows. This situation becomes worse if the FD habitat has a zero weight and is ignored in all the previous calculations.

It has therefore been assumed that some additional rules are required that over-ride some of the previous rules.

A_RULE 1: It is assumed that even if the FD habitat is not weighted it still plays an ecological role (if it is present at discharges below the maximum baseflow) and simply replaces the value of the shallower fast habitats, which may only represent a small part of the total available habitat at relatively high baseflows. This means that the FD habitat must always be included in the calculations.

A_RULE 2: The initial stress calculations for the FS and FI habitat types should be based on reference to the maximum % habitat frequency and that for all flows above that, the habitat type is ignored for the purposes of stress calculations. This means that for rivers with minimal FS or FI habitats (i.e. dominated by FD habitats) the effect on stress of FI or FS habitats would only start at quite low flows.

A_RULE 3: The basis for calculating the initial stress values for each habitat type would start when the habitat is at a maximum (stress = 0) and end when that habitat disappears at a stress value

(FDmax, FImax and FSmax) determined by the weighting factors and the parameter that defines the maximum stress for the curve as a whole. First of all the FD habitat is assigned a nominal maximum stress of 3 if the FD habitat extends below flows that are 25% of maximum baseflow, 2.5 if it only extends below 50%, 1.5 if it only extends below 75% and a stress of 1 if the FD habitat is confined to flows that 75% of maximum baseflow. If all fast habitats have a non-zero weight then the approach is that the contribution to total stress is based on the weighting factors. If the maximum stress parameter is 9, the weights are (FS:3, FI:3, FD:4) and the FD extends into flows that are 25% of maximum baseflow then the relative contributions are as follows:

FDmax = (9–3) * 4 / (3+3+4) = 5.4
FImax & FSmax = (9–3) * 3 / (3+3+4) = 1.8

If the FD weight is zero and all other values the same then the relative contributions change to:

FDmax = 3
FImax & FSmax = (9–3) * 3 / (3+3) = 3

Figure 4.1 illustrates the effects of these changes to the rule base for the Crocodile River site. One thing that is immediately noticeable is that the revised curves are much smoother and do not contain the sharp breaks of slope often observed when using the previous version of the model. This sharp break of slope had been previously noted by Dr Birkhead in several Reserve studies and was frequently over-ridden by entering the stress-flow curve data manually.

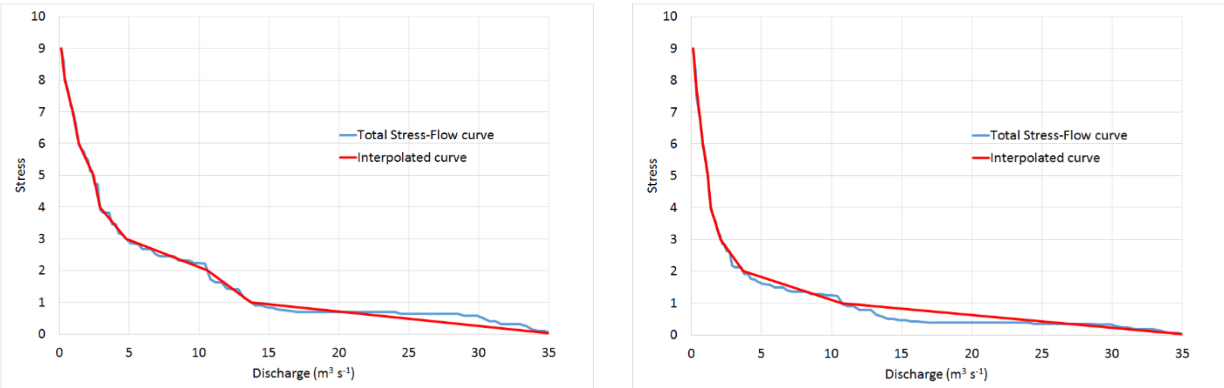

Figure 4.1 Revised stress-flow relationships (Crocodile River for the wet season) using weighting factors (FS:3, FI:3, FD:4) on the left and (FS:3; FI:3; FD:0) on the right.

4.3.2 Previous rule base for calculating the Ecological Category (A to D) stress frequency curves

The default parameters for drawing the frequency curves were never really established with any ecological meaning as this information was not made available. The parameters were also based on the use of relative shifts in the end points (maximum and minimum stress) of the curves and shapes that reflect, as far as possible, the shape of the natural flow stress curve. The exception is if the ‘align to present day’ option was used, in which case the maximum stress value was set to a value similar to the maximum present day stress and the curve shape set to reflect the shape of the present day stress curve. Experience suggests that the use of ‘shift’ type parameters was quite problematic and very sensitive to the natural stress curve position. It was decided, therefore, that the future parameter set should be based on estimating the actual maximum and minimum stress values for A to D categories.

4.3.3 Revised approach for calculating the Ecological Category (A to D) stress frequency curves

The revised approach and ecological rationale (where appropriate) is explained below as a sequence of steps that will guide the software re-coding principles.

Step 1: Determine the natural (and PDay) stress frequency curves and calculate the S-curve shape parameter from the part of the curve from 0 stress to maximum stress (i.e. do not include the flat part of the frequency curve where 0 stress occurs naturally). Step 4 must be repeated only if the stress weights change and the stress-flow relationship changes during editing, not if the category stress parameters (old 'shifts') change.

Step 2: Determine the appropriate rule base depending on the shape of the natural stress frequency curves for the main wet and dry season months (i.e. Step is applied independently to the wet and dry season months):

- 2.1: Perennial and the maximum natural stress is always less than the stress value at loss of fast habitat (typically a stress of 9).
- 2.2: Perennial but where there are periods of no fast habitat in the natural condition.
- 2.3: Non-perennial for the month being used (i.e. stresses of 10 do occur in the natural condition).

Step 3: Three separate rules are applied depending on the outcome of the assessment in step 2. All of these rules are designed to establish the maximum stress value for a D category:

- 3.1: If 2.1 (above) applies then the stress at which the deepest optimal habitat is less than 10% of the maximum frequency value (% of wetter channel width) for that same habitat (for all flows less than or equal to the maximum baseflow) is used to establish the D category maximum stress point. This was discussed extensively within the workshop and it was previously decided to use the flow and equivalent stress at the point when the deepest optimal habitat almost disappears. However, when testing this it appeared to give quite high stress values for a D category, even when the maximum natural stress was very low.
- 3.2: if 2.2 applies (i.e. perennial but periods of no fast habitats) then all the maximum stresses for the different categories are set to values between the maximum natural stress and 10 (i.e. zero flows). The exact way in which this will be implemented has yet to be determined, but is unlikely to be very sensitive at such low flows.
- 3.3: If 2.3 applies (natural non-perennial) the D line will cross the horizontal axis at a stress of 10 and at a % frequency value that is 1.5 times the duration of natural zero flows. The other category lines will cross the horizontal axis at points between the natural and D lines using the principles of relative change that have been accepted by the community of ecological specialists and are summarised in Table 4.1

Table 4.1 Principles of relative change from natural to Ecological Categories

Condition	Relative change from the next highest condition	Change value (relative to natural) for rule 3 (maximum frequency of zero flows)	Absolute value of frequency of zero flow if natural is 10%
Natural	0	0	10%
A	5	1.05	10.5%
A/B	5	1.1	11%
B	5	1.15	11.5%
B/C	7.5	1.225	12.25%
C	7.5	1.3	13%
C/D	10	1.4	14%
D	10	1.5	15%

Step 4: Determine the 'minimum' stress for D as 0.5 * max natural stress (or a default value of 5 if natural conditions are non-perennial) if the max natural stress is greater than 4. For lower natural max stress values, the D category minimum stress is set at 2 * max natural stress, with a maximum value of 2.0. This minimum value is assumed to occur at the lowest frequency when the natural stress is still zero (rather than a frequency of 100%).

Step 5: Determine the relative spacing between D and natural for all other categories and draw all of the stress curves. The relative spacing is based on multipliers of D_{stress}-0 {A:0.1, A/B:0.2, B:0.3, B/C:0.45, C:0.6, C/D:0.8, D:1.0}. This means that if the minimum stress for D is set a 5 then the ecological category minimum stress values will be {A:0.5, A/B:1, B:1.5, B/C:2.25, C:3, C/D:4, D:5}.

4.3.4 Establishing the approach for the category alignment (to present day) option

This is the option that allows an automatic adjustment to the default shift parameters to try and align the category stress frequency curves to the present day stress frequency curve. The first step is to set the maximum stress value of the selected alignment category to the same maximum stress as present day (for both seasons). The spacing between the maximum stress values for the other categories then remains the same, subject to a constraint that none of the maximum stress values can be less than the natural maximum stress. If this occurs, then all of the maximum stress values for the categories higher than the alignment category are adjusted to be higher than the maximum natural stress using the relative spacings given in Table 4.1 column 2. The maximum stress values for the other categories are not changed. This has the effects of compressing the differences between maximum stress for the categories that are between the alignment category and natural.

The minimum stress values are based on setting the D category minimum stress in the same way as discussed in 4.3.3 but using the present day maximum stress values instead of natural. The spacing for the other category minimum stress vales uses the standard method of spacing.

Finally, the full category stress curves are quantified using the curve shapes derived from the present day stress curve, rather than the natural curve shapes.

4.3.5 Using the options to limit the results to perennial or allowing non-perennial conditions.

The previous option to limit the results based on perenniality were not considered necessary given the other changes that were made to the model. The option has not been completely removed (in case it becomes necessary in the future) but it is inactive.

4.4 ECOLOGICAL SUB-MODEL FOR HIGH FLOWS

Unlike the low flow ecological sub-model, where the intention was always to refine an existing approach, the flood component (or high flow Reserve requirement) needed to be completely replaced. This was always recognized, right from the original design of the Revised Desktop Reserve model, although previously the resources were not available to achieve this.

Figure 4.2 shows a screen shot of the form for setting high flows that includes specialist inputs. The left part of the screen shows the channel cross-section used in the study (observed or desktop generated) and the stage-discharge curve used to convert depths to discharges. The middle to right side at the top of the screen shows the catchment area and options to select the catchment shape and river slope classes. These three are used to estimate a nominal value of the time to peak of the flood hydrographs using an approach designed by UKZN (Prof Smithers) for design flood hydrographs.

The process of setting the high flow requirements is based on establishing 5 flood categories and for each one specifying the following:

- The flood category number (1 to 5).
- The peak discharge (assuming hourly time intervals). This is selected by using the spin buttons adjacent to the depth label and moving the blue depth marker on the cross-section up or down until an appropriate flood depth is identified for the flood category. The red line provides a reference depth that is the equivalent of the wet season maximum baseflow quantified during the hydrology sub-model of the full RDRM.
- The frequency selection box allows the user to select inter-annual or annual events, as well as events with up to 1:5 year return periods.
- The final user input is the maximum number of events that should occur for the flood category.

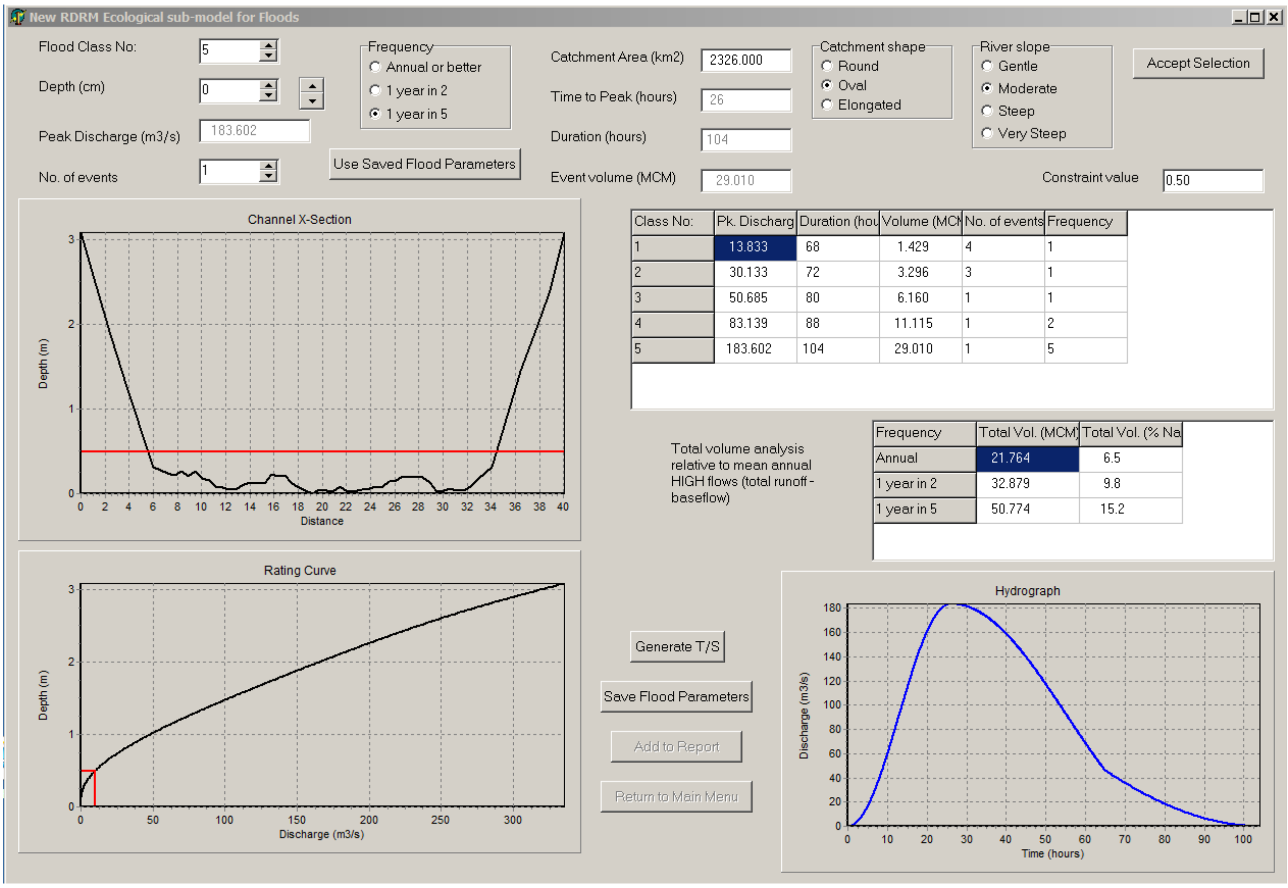

Figure 4.2 Form for setting Reserve floods and high flow requirements

As these values are changed, the entries in the Time to Peak, Duration and Event Volume displays (middle top) are updated as well as the full hydrograph shape in the lower right graph. The Duration entry represents the total duration of the hydrograph. The 'Accept Selection' button is used to add the details for the current flood category to the upper and lower tables on the middle-right of the screen. The upper table simply provides the main details of each flood category, while the lower table summarises the annual volume requirements. It is assumed that the inter-annual and annual events (typically category 1 to 3 events) are always required (assuming enough water volume is available under natural conditions), while a 1:2 year event is added for those years with frequencies of exceedance of 50% or less and a 1:5 year event replaces the 1:2 year event at frequencies of exceedance of 20% or less.

The 'Generate T/S' button is then used to check all of the requirements against the natural high flow time series and generate the time series of flood requirements for all ecological categories (A to D) on the basis on a set of rules that are briefly discussed below.

The process of deciding which category floods to include in any year, and which months to allocate them to, is based on the natural flow time series of separated high flows (no baseflows) and is quite complex. There are several stages in the analysis process that is used.

- The first step is to compare the total volume requirement for a 1:5 year return period with the natural annual high flow volume at a frequency of exceedance of 20%. Assuming this value is less than 1.0 (i.e. requirement less than natural), the ratio is used to constrain all the other requirements for an A ecological category. This means that no annual or monthly requirement calculated in the following steps may exceed the equivalent natural high flow multiplied by this ratio.
- For all other categories this constraint ratio remains the same for the monthly analysis (see below) and for all years wetter than the 20% exceedance level. For years with lower flows than the 20% exceedance level, the constraint ratio in the driest year is reduced to zero for a D category and progressively higher values for the other categories using a similar approach to that illustrated in Table 4.2. Thus, if the A category constraint is determined to be 0.6 then the others are {A/B:0.53; B:0.47; B/C:0.37; C:0.27; C/D:0.13, D:0}. The constraint ratios for all the years between the driest and the 20% exceedance level are linearly interpolated between these values and the fixed A category constraint ratio.
- The third step is to identify which of the category events can be included without exceeding the constrained annual volume limit. This is illustrated in Table 4.2 for an A ecological category where the constraint ratio is fixed at 0.61. The natural annual volumes are ranked and the table shows the lower (drier) part of the series. The shaded areas indicate which events have been included for each year and it is clear that no events are included in the 6 driest years. Table 4.3 shows the equivalent table for a D category. The first column now represents the calculated constraint ratio. For a D category, there are 11 years without any events included at all.
- The information on the events to be included in each year of the record is now passed to the monthly analysis which considers the monthly volumes and whether these are large enough (after applying the fixed constraint ratio) to allow events to be included.
- The month with the highest natural volume is used to allocate all, or part, of the largest event requirement, the second highest natural volume month used for the next largest requirement, etc. If some requirements cannot be allocated to a new month, then the residual volume for months that already have events allocated to them are used. This process inevitably means that during some months (and therefore years) there will be allocations of requirements that are lower than the initial annual analysis shown in Table 4.2 and Table 4.3 based solely on annual values. Despite this, initial testing of the approach showed that it generated acceptable results for a limited number of tests. However, these results are very likely to be dependent upon the initial constraint ratio.

The value and utility of this proposed approach was discussed at a specialist workshop and there was general agreement that it would provide a satisfactory tool for specialists in a Reserve workshop and should therefore form the basis of the RDRM approach to be applied at the desktop and specialist input levels.

Table 4.2 Part of the annual analysis for an A ecological category based on a fixed constraint ratio of 0.61, 3 category 1, 1 category 2, 1 category 3, 1 category 4 (1:2) and 1 category 5 (1:5) events (all volumes are in $m^3 * 10^6$).

Natural flow volume	Constrained max. flow volume	Total annual volume required	1 cat. 1 event	2 cat. 1 events	3 cat. 1 events	All cat. 1 and a cat. 2 event	All cat. 1 and 2 events and a cat. 3 event	All 1-3 cat. events and a cat. 4 event	All 1-3 cat. events and a cat. 5 event
11.886	7.250	6.998	0.838	1.676	2.514	3.833	6.998	13.7	20.254
11.521	7.028	6.998	0.838	1.676	2.514	3.833	6.998	13.7	20.254
10.291	6.278	3.833	0.838	1.676	2.514	3.833	6.998	13.7	20.254
9.993	6.096	3.833	0.838	1.676	2.514	3.833	6.998	13.7	20.254
9.125	5.566	3.833	0.838	1.676	2.514	3.833	6.998	13.7	20.254
8.743	5.333	3.833	0.838	1.676	2.514	3.833	6.998	13.7	20.254
8.511	5.192	3.833	0.838	1.676	2.514	3.833	6.998	13.7	20.254
7.860	4.795	3.833	0.838	1.676	2.514	3.833	6.998	13.7	20.254
7.697	4.695	3.833	0.838	1.676	2.514	3.833	6.998	13.7	20.254
7.269	4.434	3.833	0.838	1.676	2.514	3.833	6.998	13.7	20.254
6.909	4.214	3.833	0.838	1.676	2.514	3.833	6.998	13.7	20.254
6.704	4.089	3.833	0.838	1.676	2.514	3.833	6.998	13.7	20.254
6.691	4.082	3.833	0.838	1.676	2.514	3.833	6.998	13.7	20.254
6.564	4.004	3.833	0.838	1.676	2.514	3.833	6.998	13.7	20.254
5.583	3.406	2.514	0.838	1.676	2.514	3.833	6.998	13.7	20.254
5.492	3.350	2.514	0.838	1.676	2.514	3.833	6.998	13.7	20.254
5.492	3.350	2.514	0.838	1.676	2.514	3.833	6.998	13.7	20.254
5.303	3.235	2.514	0.838	1.676	2.514	3.833	6.998	13.7	20.254
5.273	3.217	2.514	0.838	1.676	2.514	3.833	6.998	13.7	20.254
5.269	3.214	2.514	0.838	1.676	2.514	3.833	6.998	13.7	20.254
4.972	3.033	2.514	0.838	1.676	2.514	3.833	6.998	13.7	20.254
4.668	2.847	2.514	0.838	1.676	2.514	3.833	6.998	13.7	20.254
4.212	2.569	2.514	0.838	1.676	2.514	3.833	6.998	13.7	20.254
3.925	2.394	1.676	0.838	1.676	2.514	3.833	6.998	13.7	20.254
3.791	2.313	1.676	0.838	1.676	2.514	3.833	6.998	13.7	20.254
3.648	2.225	1.676	0.838	1.676	2.514	3.833	6.998	13.7	20.254
3.626	2.212	1.676	0.838	1.676	2.514	3.833	6.998	13.7	20.254
2.473	1.509	0.838	0.838	1.676	2.514	3.833	6.998	13.7	20.254
2.448	1.493	0.838	0.838	1.676	2.514	3.833	6.998	13.7	20.254
1.791	1.093	0.838	0.838	1.676	2.514	3.833	6.998	13.7	20.254
1.476	0.900	0.838	0.838	1.676	2.514	3.833	6.998	13.7	20.254
1.408	0.859	0.838	0.838	1.676	2.514	3.833	6.998	13.7	20.254
1.352	0.825	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
1.069	0.652	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.970	0.592	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.937	0.572	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.924	0.564	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.514	0.314	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254

Table 4.3 Part of the annual analysis for a D ecological category based on an annually varying constraint ratio of between 0.61 and 0, 3 category 1, 1 category 2, 1 category 3, 1 category 4 (1:2) and 1 category 5 (1:5) events (all volumes are in $m^3 * 10^6$).

Constraint ratio	Constrained max. flow volume	Total annual volume required	1 cat. 1 event	2 cat. 1 events	3 cat. 1 events	All cat. 1 and a cat. 2 events	All cat. 1 and 2 events and a cat. 3 event	All 1-3 cat. events and a cat. 4 event	All 1-3 cat. events and a cat. 5 event
0.330	3.945	3.833	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.323	3.720	2.514	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.314	3.231	2.514	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.305	3.047	2.514	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.296	2.708	2.514	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.287	2.509	1.676	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.278	2.366	1.676	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.269	2.115	1.676	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.260	2.002	1.676	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.251	1.825	1.676	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.242	1.673	0.838	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.233	1.563	0.838	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.224	1.500	0.838	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.215	1.413	0.838	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.206	1.151	0.838	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.197	1.083	0.838	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.188	1.034	0.838	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.179	0.951	0.838	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.170	0.898	0.838	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.161	0.850	0.838	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.152	0.758	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.143	0.669	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.135	0.566	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.125	0.492	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.117	0.442	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.108	0.392	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.099	0.357	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.090	0.221	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.081	0.197	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.072	0.128	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.063	0.092	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.054	0.075	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.045	0.060	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.036	0.038	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.027	0.026	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.018	0.016	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0.009	0.008	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254
0	0	0	0.838	1.676	2.514	3.833	6.998	13.7	20.254

4.4.1 Implementing a Desktop version of the new approach to floods

The following bullet points lists the parameter or input requirements for the new approach to floods to be applied at the desktop level. The list also offers some suggestions about how these requirements could be sourced.

- Catchment area, channel slope class and catchment shape class. It is considered that these will be generally available to any trained user from existing databases or a relatively simple analysis of Google Earth and standard, readily available, GIS coverages. These parameters are used to estimate the time to peak.
- The number of different category floods to be defined and their frequency. Based on previous experience it was decided to use 4 category 1 events (inter-annual), 3 category 2 events (inter-annual), 1 category 3 event (annual), 1 category 4 event (1:2 year return period) and 1 category 5 event (1:5 year return period).
- The peak discharges of the different category events. The analysis of results from previous assessment revealed relatively consistent relationships between the different category flood peaks and estimates of bankfull flow and the coefficient of variation for the wet season month, and these were initially used to provide peak discharges (at the desktop level).

The predictive ability of this Version 2 of the Revised Desktop Reserve Model (RDRMv2) was assessed at a workshop in October 2017 by comparing its results with those from previous assessments of higher confidence. Approximately 72 EWR sites were considered, which included a range of Ecological Categories and hydrological characteristics. The data from previous assessments were compiled into a ‘comparative’ spreadsheet to facilitate further analyses, and included *inter alia*, hydrological variability index, maximum base flow and bankfull discharge. Where not available from these previous assessments, the 6-parameter ‘s-curve’ that characterises the rating (stage-discharge) relationship (in the RDRM) was fitted.

The approach used to estimate peak flow events that was based on proportions of the bankfull discharge and hydrological variability index (see above), was refined. The Nash-Sutcliffe efficiency was used to calibrate coefficients in power relationships between flood peak estimates (RDRMv2) and those from previous EWR assessments. The independent (input) parameters in the refined desktop model are the maximum base flow discharge (wettest month), bankfull discharge, and coefficient of variability for the wettest month in the naturalised times series. The improvement in the flood peak (and hence high flow EWR) predictions may be inferred from the substantial reduction in the scatter between Figure 4.3 (pre-workshop) and Figure 4.4 (post-workshop).

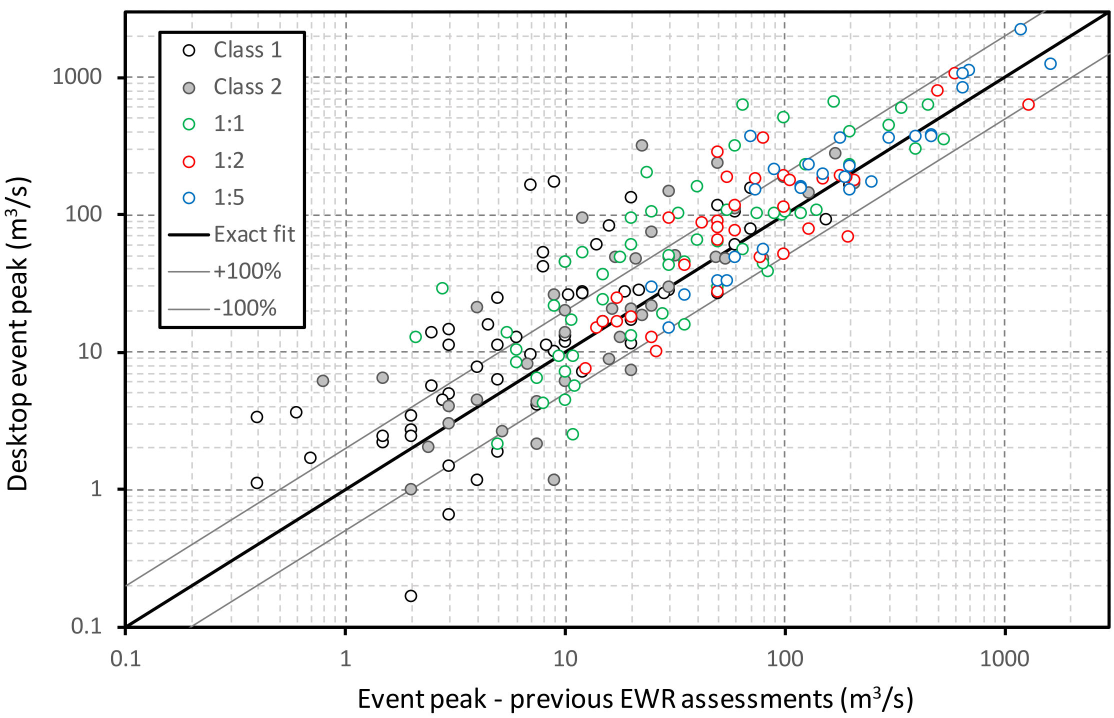

Figure 4.3 Plot of event peaks as estimated by the RDRMv2 (pre-October 2017 workshop) against values from previous (higher confidence) EWR assessments for numerous EWR sites

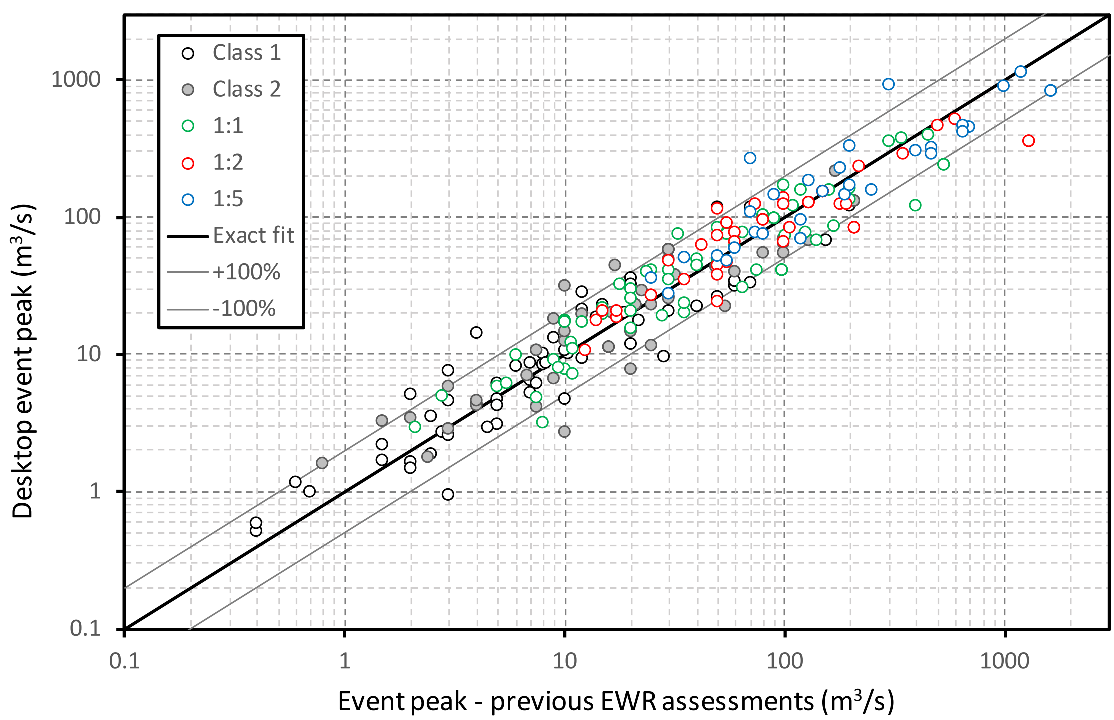

Figure 4.4 Plot of event peaks for various flood classes as estimated by the RDRMv2 (post-October 2017 workshop) against values from previous (higher confidence) EWR assessments for numerous EWR sites

The empirical equations for the peaks (QP) of the different flood classes are given below (MBF = maximum wet season baseflow, BFQ = bankfull discharge, CV = coefficient of variation of monthly flows of the wettest month) and are based on an analysis of previous EWR determinations in South Africa:

Class 1: $QP1 = 2.6 * MBF^{0.736}$

Class 2: $QP2 = 3.44 * MBF^{0.685} + QP1$

Class 3 (annual event): $QP2 = 4.3 * MBF^{0.6} + 0.006 * (BFQ / (1+CV))^{1.29} + QP2$

Class 4 (1:2 yr event): $QP3 = 1.47 * (BFQ / (1+CV))^{0.62} + QP3$

Class 5 (1:5 yr event): $QP4 = 2.5 * (BFQ / (1+CV))^{0.74} + QP4$

- The time to peak and total hydrograph duration vary with the flood peak magnitude.
- In the approach for generating the time series, the 1:5 year annual requirement is checked against the equivalent natural high flow volume to determine the A ecological category constraint ratio. Some preliminary tests suggested that these values were very low (often less than 0.2) and unrealistic values for constraining the flood requirements relative to natural flow. It is also possible to check the annual 1:2 year volume and the 1:2 and 1:5 event requirements against the maximum monthly flows during the equivalent 1:2 and 1:5 year return period years. The largest of these could be used. It was therefore decided that a minimum value of (possibly) 0.5 should be used. It will also be necessary to determine what a maximum value should be.
- If the 1:5 and 1:2 annual or monthly fractions are too low (say below 0.2), or too high (say above 0.7) then the software warns that the XS maximum discharge (hence the size or other hydraulic parameters) is possibly too small or too large. If this warning is ignored it should be included in the ‘report’.

The flood events are used within a quite complex algorithm (discussed in the previous section) to spread the volumes throughout the time series based on the characteristics of the natural high flow regime. The key issue is that the requirements are allocated to months within the time series where high flow volumes occurred under natural conditions. The whole approach is quite dependent upon the links between the channel cross-section characteristics (and ultimately the estimated bankfull discharge) and the natural high flow regime. If these are not in balance the whole approach used to determine the time series can be compromised.

The main differences between the flood requirements for different ecological categories lies in how many of the defined flood event hydrographs (and their volumes) are included in the time series. This means that the flood event hydrographs are common to all the categories, but they may not all get included in the final time series, particularly for the lower protection categories.

During some testing of the model in Tanzania, it became clear that the approaches being used are not appropriate for rivers with quite low CV values, nor for large rivers with strongly seasonal high flow regimes (i.e. not individual events separated by low flow periods, but a general rise and fall of flow throughout the wet season). This has been allowed for in the model by calculating the default number of annual or less events (classes 1 to 3) based on the number of months that can be considered to be the wet season in the natural flow regime. The duration of the events is then assumed to be the whole month (720 hours) and the volumes calculated accordingly. However, the peak discharge values are still based on the same equations given above and this requires more attention in the future. These changes are unlikely to impact on any Reserve determinations in South Africa (with the possible exception of the Limpopo River) as the conditions that are required before this alternative approach is used rarely exist in the country.

A further issue that was highlighted by the Tanzanian experience is that the model does not adequately account for flood requirements of rivers with large floodplains where out-of-bank flows are likely to be ecologically important. While it is possible that the default estimates may generate 1:2 and 1:5 year floods that are greater than bankfull (due to low CV values), there is no guarantee that this will happen. If the option to set the flood peaks manually is chosen, then all of the peak values have to be below bankfull as they are quantified by setting a depth within the channel cross-section (the blue horizontal line in Figure 4.2). The only alternative with the current version of the model is to extend the channel cross-section to include the floodplain. However, the hydraulics sub-model and specifically the way in which the stage-discharge relationship is calculated would then be inappropriate. The overall conclusion is that, if floodplain flows are to be accounted for, the high flow component of the model will have to be revised to allow for out-of-bank flood flows.

5 CAPACITY BUILDING CURRENT AND ONGOING

The capacity building programme designed with DWS and WRC is summarised below:

The objective capacity building was to provide extensive training to three DWS officials:

- Ms Tinyiko Mpete
- Ms Gladys Makhado
- Mr Molefi Mazibuko

Three training sessions with these officials took place in the R4A offices during August 2017, September 2017 and January 2018. These officials also participated in a week work session in Grahamstown during the final testing and calibration of the model.

The detail of the training a is provided below.

1 INTENSIVE TRAINING OF THREE SELECTED RDM OFFICIALS

Identified trainees: Tinyoko Mpete, Gladys Makhado, Molefi Mazibuko

1.1 Preparatory training 1

Objective: SPATSIM Introduction with specific emphasis on loading hydrological data and setting up of sites within SPATSIM for use in the RDRM. Links and use of Google Earth will also be explored.
Date: 2 days to be selected by DWS in the week of 28 August to 1 September.
Venue: R4A offices, Pretoria
Outcome: Trainees to be comfortable loading data into SPATSIM and working with Google Earth.

1.2 Preparatory training 2

Objective: Become comfortable in understanding and using the relevant sub-models in the current version of the RDRM. Links and use of Google Earth will also be explored. PESEIS database will be unpacked with specific emphasis on links to RDRM. Refresher on EcoClassification to be included.
Date: 2 days – 12 and 13 September 2017.
Venue: R4A offices, Pretoria
Outcome: Trainees to be comfortable to run the current version of the model so that they can fully participate in the October final RDRM testing workshop.

1.3 Implementation and testing of the RDRM with specific emphasis on the ecological data integration and the new high flow method

Objective: This workshop is part of the specialist activities to be undertaken by the team. Participation of the trainees will allow trainees to be part of the testing exercise, i.e. running of the model and testing against existing EWR results. Furthermore, it will provide trainees with an understanding of the issues, complexities and intricacies of the model and how these will be addressed.
Date: 5 days: 23 to 27 October 2017. These are fixed dates based on deliverable date and availability of the team.
Venue: IWR in Rhodes University, Grahamstown

Outcome: Trainees will have a good understanding of the intricacies of the model and will be comfortable running the new model in its existing format.

1.4 Manual testing and refinement

Objective: The final model was available as well as a draft manual. The trainees tested the manual by running the final model to determine whether any steps are excluded, not clear or must be adjusted. The trainees therefore provided the final input for finalisation of the manual.
Date: 2 days in the week of 22 to 26 January 2018.
Venue: R4A offices, Pretoria
Outcome: Trainees will be sure that they have the support they need to run the RDRM. They will be part of the trainer groups providing the detailed training for other RDRM officials and also providing in-house support for the use of the model.

2 INFORMATION SESSION: UNDERSTANDING OF RESULTS AND IMPLICATIONS FOR USE (April 2018)

This session was previously referred to as the 'broad' training to be provided to DWS senior managers. This session ran over two days consisting of a first day which will be an information session on the model, the outcomes, and the uses within that. It was followed by a session which focused on the requirements in terms of the use of the results with a specific emphasis on the templates for the Preliminary Reserve, the Classification and RQOs (with relevance to the Reserve results included in this), and the Reserve.

3 INTENSIVE TRAINING SESSION

Objective: Train RDM officials in the use of the model.
Date: 5 days 14-18 May 2018.
Venue: Roodeplaat Training Facility, Pretoria
Programme: The first day and a half covered SPATSIM training which included the loading of hydrological data and managing other types of data within SPATSIM. This was followed by specific training in the use of the RDRM. Part of the SPATSIM training was undertaken prior to the RDRM training as was done in-house by the DWS trainers.
Outcome: DWS will have officials who are comfortable running the model and will have three persons that can provide in-house assistance and training to the group trained during this session.

At this stage, DWS is in the position to provide in-house training on the model. Additional information on the capacity building is provided in chapter 6.

6 CONCLUSIONS AND RECOMMENDATIONS

One of the topics that was discussed during the workshops that were held for this project centred around the future use of the model and SPATSIM within the Department of Water and Sanitation (DWS). The key issue is that several individuals and outside organisations (consultants) could be doing Reserve determinations based on their own setups of SPATSIM, while DWS needs to maintain a central database that contains all the information and data required to repeat a run of the model for a specific site. The following recommendations are made to facilitate this process.

- Establish a position(s) within DWS for a person or persons who will be responsible for maintaining the central database. This should not be considered as an IT issue, but is an issue of maintaining the integrity of the national database of Reserve determinations.
- Any individual or organisation (remote user) tasked with doing a Reserve determination will have to obtain the current version of the SPATSIM application database from the central database administrator. This is a simple matter of copying the application (currently called Nationalv2) folder from one computer to another and can be done over the internet or locally.
- When a remote Reserve determination has been completed, the new information that has been generated is exported to text files (using the <Attribute>, <Export Attributes> menu option for all the appropriate attributes) by the remote user. The remote user then edits the exported data so that only the data for the new sites that they have generated remains. These files, as well as the locations of the new Reserve sites are then passed to the DWS central database administrator.
- The DWS central database administrator then creates the new EWR Site points (using <Features>, <Point Features>, Add Points>) with exactly the same names used by the remote user and then uses the various <Attribute>, <Import or Edit> options to import the data from the text files supplied by the remote user.
- A further issue relates to the repeatability of any Reserve determination and a record of any changes that are made if a site is re-visited. The person or persons responsible for maintaining the database need to establish protocols for data archiving and ensuring that the full history of any Reserve determination is retained in the database and can be retrieved.

Some of the options in SPATSIM have been recently updated to facilitate this process (for example, there was previously no option to import memo type attributes and that facility has now been included). The export/import process needs to be fully explained to all the remote users to ensure that all of the critical information used and generated within a Reserve determination is captured to the central database. This includes all the required inputs to the model (site ID name, ecological and hydrology/hydraulic parameter sets, natural flow time series data), as well as some of the critical optional inputs/outputs (saved channel cross-section, report memo) and the optional inputs/outputs if they have been used (High flow parameters, observed channel cross-section, stage-discharge parameters, present day and scenario flow time series data).

Another point that has been frequently raised over the years that the Institute for Water Research (IWR) has been developing SPATSIM and the associated models (including the RDRM), is the long-term sustainability of the software. All that can be said at this time is that the Hydrology Group of the IWR remains committed to supporting the software and its future improvement. For example, we have recently made some changes so that a new utility is available on the front screen of SPATSIM to facilitate updates from the IWR web page (instead of having to go to the web page manually). This will become available to users after they complete their next download directly from the web page.
A further development that we are currently discussing is the development of short training videos to support the existing user guidance material. The IWR has no financial support for this development

and therefore the relevant staff members have to find some free time from other projects to be able to develop these videos. It is therefore not likely to happen in the immediate future, but will happen gradually. We are also discussing the possibility of running more regular training and update courses on both the basics of using SPATSIM, as well as running some of the models (e.g. RDRM and the Pitman rainfall-runoff model). These training courses would be open to any participants but would be run on a commercial (fee paying) basis, as the IWR has no alternative financial resources to support staff time for running such courses.

With respect to the longer-term ‘ownership’ and availability of the software code, the IWR is prepared to allow others access to the source code (written in Delphi, using SQlite database drivers) upon request. However, we have to warn those who might like to access this code that it is very large, and very complicated and it would take a new user a very long time to become sufficiently familiar with the code to be able to make anything but cosmetic changes. It should be recognised that any software system has a life time after which it tends to be replaced by newer approaches. The executable files and software of SPATSIM could be around for many years to come, but we have to recognise that the two main code developers (Prof Denis Hughes and Mr David Forsyth) have a limited working lifespan, after which it is unlikely that new developments can be made. The IWR is, however, open to suggestions for other approaches that might make the code development more sustainable.

One of the issues discussed in various meetings was the future name of the model and the fact that it serves a purpose that is more than just a desktop Reserve determination approach, as there are many places where expert intervention can be used to re-calibrate the model outputs. Using the word ‘Reserve’ in the name of the model could also be misleading for users outside of South Africa who are not aware of the link between the use of the word and the more general term of environmental flow or water requirements. One possible name could be CEFAM (Comprehensive Environmental Flow Assessment Model), but other names are possible.