Western Cape Government

MANAGEMENT UNIT CONTROL PLANS FOR THE HOLSLOOT, KARATARA AND KEURBOOMS CATCHMENTS

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MANAGEMENT UNIT CONTROL PLANS FOR THE HOLSLOOT, KARATARA AND KEURBOOMS CATCHMENTS

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ACRONYMS	DEFINITIONS
AHP	Analytic Hierarchy Process
CSIR	Council for Scientific and Industrial Research
DEA	Department of Environmental Affairs (now Forestry, Fisheries and Environment)
DEA&DP	Department of Environmental Affairs and Development Planning
DEA-NRM	Department of Environmental Affairs - Natural Resource Management programmes (now Forestry, Fisheries and Environment)
DEFF	Department of Environment, Forestry and Fisheries
DWS	Department of Water and Sanitation (now Human Settlements, Water and Sanitation)
EIIF	Ecological Infrastructure Investment Framework
GCTWF	Greater Cape Town Water Fund
GRI	Garden Route Initiative
GRNP	Garden Route National Park
IAPs	Invasive Alien Plants
MAR	Mean Annual Runoff
MCA	Mountain Catchment Area
MIU	Mapped Invaded Unit
MUCPs	Management Unit Control Plans
NBA	National Biodiversity Assessment
NBAL	Acronym for invaded areas that have had at least one treatment
NRM	Natural Resources Management
NWM5	National Wetland Map version 5
SANBI	South African National Biodiversity Institute
SANParks	South African National Parks
WfW	Working for Water

Preface – please read first

In this report we have noted that the MUCP tools resource estimates should not be considered as definitive for a variety of reasons. Two of the main ones are discussed below. They need to be borne in mind when assessing and interpreting the MUCP tool outputs for the different catchments.

The first issue is the poor mapped data on the state of the alien plant invasions for part of all the catchments concerned. The 2010 NIAPS dataset was not intended for use at this scale and was mainly mapped in 2007 which makes too out of date to be usable. The mapped data for the Holsloot catchment varied. The data for the areas managed by CapeNature is reasonable and mapped at their mini-compartment level. In the rest of the catchment, mainly the lower part, we have recent NBAL records but nothing else. We updated the data for the upper, south-eastern part of the catchment, bordering on Elandskloof, to include the recent invasions by pines. For the Karatara catchment we have satisfactory for the CapeNature areas (Goukamma Reserve) but poor data for the rest of the catchment which was last mapped in 2008 (Vromans et al., 2010). We have used a desktop update of the 2008 mapped dataset that was prepared in 2018 (Paul Buchholz personal communication March 2020). The recently burnt areas in the catchment were updated using our knowledge of the effects of fires on the species and the state of the invasions. We followed a similar process for the Keurbooms catchment where the CapeNature mapping covers only a small fraction of the total area. We have low confidence in these outputs because of the low confidence we have in the data on alien plant invasions. This in turn will lead to poor estimates of the resources required to bring the densities down to acceptable levels and of the potential gains in river flows. The result is that our confidence in the estimates of the resource requirements generated by the model is low.

The second issue is that we have identified a problem in the MUCP tool's calculations. The data are initially read in correctly and the species are correctly matched to the Mapped Invaded Units and the NBALs they occur in. However, when the planning routines are executed, it seems that some of the species data are lost so that the calculations of the resources required for treatments and the water flow losses are underestimated. The visualisations also show that invasion data are missing from some of the areas we know are invaded. The software developer is looking into the causes of this problem and will provide us with a new version, which resolves this issue, in the near future.

Given this, what we want you to focus on for this initial round of comments is the following:

- Are the datasets we have used to represent the criteria and sub-criteria in the model appropriate?
- Are the areas that have been prioritised by the multi-criteria AHP model, and by the MUCP system, in line with your expectations?
- Please treat the resource requirements and allocations for the compartments as illustrative until the issue of the incorrect calculations has been resolved.

1 BACKGROUND

The Provincial Department of Environmental Affairs and Development Planning (DEA&DP) in the Western Cape commissioned the CSIR to develop an Ecological Infrastructure Investment Framework (EIIF), beginning in 2018. The purpose of this Framework is to guide decision-makers from both the private and public sector in making choices around where – and how – to invest in order to promote the resilience of the Western Cape's ecological infrastructure (EI) (DEA&DP, 2019). One of the components of the EIIF project was the *development of Management Unit Control Plans for at least three identified priority areas (which do not have current MUCPs)*. This report introduces the MUCP approach and system, briefly describes the process of developing such a plan, and briefly describes each of the three MUCPs.

The prioritisation of the quaternary catchments of the Western Cape is described in detail in the prioritisation report (DEA&DP, 2019) and only a brief summary of the prioritisation process and outputs is provided here. The EIIF project team held a series of stakeholder workshops to define a vision (i.e. desired future state) for the EI in the Western Cape, identify the critical EI, the major threats to EI, and the development of a prioritisation model to identify which catchments should be selected for investment in the restoration of the different kinds of EI. Information on the top priorities was integrated into the EIIF to indicate to potential investors where they should target investments aimed at achieving the objectives of the EIIF. One of these objectives is to: *to improve water quality and quantity in support of people's health and livelihoods in the province, by controlling the threat of alien invasive plants specifically and improving the ecological status of rivers, wetlands and estuaries more generally*. The top priority catchments were assessed to select the three catchments for which MUCPs would be developed. A co-benefit of controlling invasive alien plants (IAPs) is that this will also help to reduce fuel loads and, thus, the fire hazard and risk. This in turn could reduce the flood risk if high fuel loads would have resulted in severe fires over a substantial part of the upstream catchment area (Le Maitre et al., 2014). This helps achieve another goal of the EIIF: *reduce the vulnerability of people, property and the environment to the threat of uncontrolled wildfires.*

Two Water Source Areas (WSAs) (Le Maitre et al., 2018) were identified as priorities for investment in MUCPs, namely the Outeniqua-Tsitsikamma and the Boland. Two catchments within the Outeniqua-Tsitsikamma WSA had already been selected by DEA&DP for the development of "Payments for Ecosystem Services" initiatives for IAP control, namely the Karatara and Keurbooms River catchments (DEA&DP, 2018a). Although a business case was developed for IAP clearing for each catchment, which showed that there would be a positive outcome, there was little information on the resources and time-period required to bring the IAPs under control, and no priorities for clearing had been established. Therefore, it made sense to build on the existing groundwork and develop an MUCP for each of these catchments.

The key catchments in the Boland WSA that supply the city of Cape Town, other Boland towns and irrigated agriculture, are already incorporated into a business plan developed by the Greater Cape Town Water Fund (GCTWF). Although this plan includes the Theewaterskloof catchments which feed the dam, it excludes the other catchments which feed the economically important Breede River system (BGCMA, 2015; DEA&DP, 2017; Seeliger et al., 2018). The prioritisation process identified one of these other catchments, namely the Holsloot River, as a priority for investment because of its high mean annual runoff (MAR) and the current and future impacts of IAPS on the runoff. This catchment also falls in the portion of the upper Breede where the farmers are actively involved in IAP control with the support of LandCare

(Schachtschneider, 2016). Again, it made sense to build on the existing initiatives, so the Holsloot River catchment was selected for the third MUCP.

This report introduces Management Unit Control Plans and presents outcomes of the workshops and the MUCPs developed for each of the catchments. It is critical that readers of this report recognise that this report focuses on one example of the results of the workshops and the outputs generated by the MUCP tool. The MUCP tool outputs shown here are one output from a dynamic invasive alien plant treatment planning support system. If the priorities are changed, or the cost models are modified then the outputs will change and other priorities can be generated. The MUCP planning system's dynamic nature also allows it to take account of changing circumstances relatively easily. The planning of the clearing in the catchment could be done with spreadsheets but it would be laborious and very time consuming. A single large wildfire in the catchment would nullify all that planning but, by making simple updates to the invasive species information and adjustments to the veld age in the MUCP tool's input datasets, the users can be ready with a new plan within days. The stakeholders in these plans should review the outputs of the MUCP system for their catchments, and can change them where necessary, to generate a different plan. They can also do this from time to time as the clearing project (or projects) progresses.

2 MANAGEMENT UNIT CONTROL PLANS

Achieving effective control of invasive alien plants within a given area, province or country is difficult as has been shown by a number of studies (Kraaij et al., 2017; McConnachie et al., 2012; van Wilgen et al., 2016, 2012). There are many reasons for this (Fill et al., 2017), but one of the basic obstacles is being able to obtain a realistic understanding of the resources that will be required, and the associated time-frames, for the control programme to achieve effective control within a given area. Another is being able to establish a clear and transparent rationale for prioritising areas for clearing given that the available resources will not be sufficient to deal with all the invasions at the same time. The idea of a Management Unit Control Plan has its origin in the management plans developed for Mountain Catchment Areas (MCAs) by the then Department of Forestry in the first half of the 20th century. When the Working for Water Programme (WfW) was launched in 1995 with its focus on the protection of water resources, the logical unit for developing clearing plans was one or more quaternary catchments. The CSIR already had experience in developing a software package known as the Catchment Management System (CMS) for MCAs (Le Maitre et al., 1993; Richardson et al., 1994) and was commissioned to develop management plans for a number of river systems which incorporated an elementary prioritisation (e.g. Gelderblom et al., 1997).

However, Working for Water later abandoned this systematic, catchment-level approach and clearing priorities were left to the project managers, who generally did not adopt a systematic approach to identifying the priorities for clearing. Some managers within WfW recognised the problems created by this shortcoming and addressed this at two levels, both following participatory processes. The first was to establish priorities for clearing at the WFW regional level, equivalent to a province (Forsyth et al., 2012). The second focused on developing a software system to support the development of long-term, strategic management plans for a given area, be it a catchment, protected area, municipality or conservancy. The plans were called Management Unit Control Plans. They had to take into account all the invasions within the area of interest, their species composition, density, location and landscape setting, provide a reasonable estimate of the clearing costs over a 20-year period, and a prioritised treatment schedule for the areas to be treated. The thinking behind the software system has its origins in those developed for forest plantation management by forestry companies, which did detailed costing, and the CMS described above, with a focus on IAP control. The system links spatial and non-spatial datasets and uses their attributes to determine the resources required for control. It also integrates a prioritisation model, which determines the sequence in which the management units (compartments) will be treated. The resource requirements are determined by the Working for Water programme workload norms, and a costing model supplied by the user or the default (WfW costs and rates). The MUCP system is complemented by another system for Annual Plans of Operations, which does the scheduling of contracts and detailed estimates of the associated resource requirements. This report focuses on the MUCP software system.

The datasets used by the MUCP system comprise:

- Four GIS data layers:
    - Polygons for all the invaded areas in the catchment (Mapped Invaded Units (MIUs)) and an attribute indicating whether they are riparian or not
    - Polygons for any invaded areas that have been treated (NBALs) with information on the last treatment date and type
    - Polygons with the boundaries of the permanent management units (compartments) that are used to prioritise and schedule operations and track progress.
    - The union of the three layers above to enable the software system to identify the spatial relationships between the three layers above
- Three spreadsheets (attribute files):
    - The species in each MIU with their density, age class and the MIU identification code
    - The species in each NBAL with their density, age class and the NBAL identification code
    - The scores for the priority criteria for each Compartment

The MUCP software can be downloaded from a site maintained by Andrew Wannenburgh (awannenburgh@environment.gov.za) of the Operational Support and Planning Directorate in the Natural Resource Management programmes of the Department of Forestry, Fisheries and Environment (https://sites.google.com/site/wfwplanning/monitoringandevaluation). The software is supplied with a test dataset with examples of each of the datasets described above. There is also a manual for the MUCP system to help users install and operate the system. Potential users will require Geographic Information System software, or access to someone who has access, to generate the shapefiles for their own area of interest. There are freeware GIS software systems that can produce the datasets required by the MUCP software.

3 DEVELOPING AN MUCP

The MUCP system can be used by a single organisation but, since catchments are rarely owned by a single organisation, the best approach is a participatory one involving at least the key landowners and any other organisations with a stake in the clearing of IAPs to protect and/or restore EI. The participatory approach is essential because all the affected parties need to be involved in the clearing and, therefore, need to commit themselves to the implementation of the MUCP. The prioritisation process also facilitates engagement between the participants because they are the ones who determine the goal and what are the most important benefits from the EI that will be protected through IAP management. This facilitates their agreement with the priorities assigned to different areas for clearing in the finalised MUCP.

We convened two workshops, one for the Holsloot and a combined one for the Karatara and the Keurbooms. Combining the latter two made a lot of sense because the same landowners and organisations are present in both catchments. We obtained the contact details for a wide range of stakeholders in each of the catchments from various sources and contacted them about the workshops. The invitations include a brief description of the purpose and intended outputs from each workshop and suggested possible dates for the workshops. The workshop for the Holsloot was held on the 5th of November at the Sneeukoppie Hall at the Goudini Wine Cellar, near Rawsonville. The workshop for the Karatara and Keurbooms was held on the 21st of November at the Sedgefield Council Chambers in Sedgefield. In each case, the process we followed was similar, beginning with the welcome and introductions:

- Aims of the workshop
- The AHP method and MUCP system (presentation and discussion)
- An example of a prioritisation model developed for an area (presentation and discussion)
- Important invasive alien plant species in each catchment (discussion)
- Establish a goal for the MUCP (interactive)
- Identify and agree on criteria (objectives) and sub-criteria (sub-objectives) for prioritising areas within the catchments (interactive)
- Pairwise comparisons of criteria and sub-criteria for each catchment (interactive)
- Discussion of relevant and available datasets for Karatara and Keurbooms catchments
- Clarify how the catchments will be divided into management units (compartments)

Each of the workshops was characterised by extensive discussions between the participants and the team as well as between the participants. Further details are given in the sections dealing with each of the MUCPs.

4 HOLSLOOT

4.1 CATCHMENT DESCRIPTION

The Holsloot River is located in the Upper Breede and comprises quaternary catchments H10K, which covers 19 405 ha and has a mean annual runoff (MAR) of 624 mm (120 million m^3), and H10L which covers 9 568 ha and has a MAR of 93.8 mm (Bailey and Pitman, 2015). The watershed of the catchments is located in the Wemmershoek, Dutoitskloof and Stettynskloof mountains with the highest point being Wemmershoek Peak at 1 766 m. The montane areas are very rugged and there is limited access beyond the road up to the dam wall. The steep upper slopes and high rainfall in the catchment result in the catchment being responsive to heavy rainfall, which can result in floods and flood damage downstream on the Holsloot River. The dominant upland vegetation is Hawequas Sandstone Fynbos, with azonal Fynbos Riparian Vegetation along the streams and rivers above the dam (Rebelo et al., 2006). There are also small areas of threatened Boland Granite fynbos in the catchments, notably in the valley bottom above the Stettynskloof Dam. The floodplain or valley bottom vegetation from where the valley opens up is threatened Breede Alluvial Fynbos (Rebelo et al., 2006), which has been almost completely replaced by farmlands, urban areas and other disturbed land cover types (BolandEnviro, 2016).

The main stem of the Holsloot River is about 45 km in length from its source to the confluence with the Breede River. The catchment includes the Stettynskloof Dam, which has a capacity of 15 million m^3 and supplies water to the town of Worcester for domestic and industrial use.

The lower boundary of the catchments extends to include the Brandvlei Dam, a large irrigation dam, which is supplied with water from the Holsloot River via a canal. The Holsloot River system also supplies water to the farmers downstream where a weir was constructed to replace previous abstraction structures, and to supply about 6.5 million m^3 per year for irrigation (BolandEnviro, 2016). In return for this investment, the farmers have undertaken to clear and rehabilitate invaded riparian areas along the Holsloot River from the dam to the confluence, a distance of about 20 km. Most of the upper catchment falls into the Limietberg Nature Reserve (formerly Hawequa and Theewaterskloof NRs), which is managed by CapeNature.

The upper catchment has extensive invasions of *Hakea sericea*, mainly above the dam in the Stettynskloof River catchment, and of *Pinus pinaster,* which occurs mainly in the south-western portion which adjoins Kaaimansgat (also known as Elandskloof). The riparian areas had dense invasions dominated by *Acacia mearnsii* (Black wattle) with some areas with eucalypts, especially in the lower reaches (BolandEnviro, 2016). Large areas of riparian invasion have already been cleared, and the clearing is continuing but the clearing in the upper catchment has not been effective in reducing the extent and density of the invasions (Deon Rossouw, CapeNature, personal communication 2019). Based on the mapping done for the National Invasive Alien Plant Survey in 2007 (Kotzé et al., 2010), the reduction in the MAR was estimated to be about 27% (Le Maitre et al., 2013), and by 2032 could reach 32% (D.C. Le Maitre unpublished data).

The mapped information on invasions is considered satisfactory for this catchment but needs improvement to provide greater confidence in the system outputs.

4.2 WORKSHOP AND MODEL DEVELOPMENT

The workshop was held on the 5th of November in the Sneeukoppie Hall at the Goudini Wine Cellar near Rawsonville. The participants included representatives from CapeNature, provincial LandCare, organised agriculture and the local municipality (see attendance register in Appendix A). After the introduction to the workshop and the presentation on the AHP and the MUCP tool, the first step was to collectively define a goal for the management of the IAPs in the catchment that was SMART (Specific, Measurable, Assignable, Realistic and Time-bound). After some discussion about the importance of water supply and security, fires and fire risks, IAPs and soil erosion, the participants defined the following goal:

By 2040 a collaborative management effort has sustainably reduced the extent and density of IAPs to increase water production, maintain an acceptable fire regime, and protect biodiversity in the Holsloot catchment

The next steps were to establish criteria for determining priorities for clearing i.e. why some areas should be cleared before others. This step was done interactively using the ExpertChoice®[1] software to facilitate the process and resulted in a multi-criteria (Analytic Hierarchy Process) model. Once the criteria were agreed on, we interactively compared and weighted the criteria and sub-criteria using a verbal scale which the software converts to numerical values. The model that was agreed to at the workshop comprises two main criteria, each with a set of sub-criteria (Figure 1).

[1] https://www.expertchoice.com/2019; we are using version 11 of the stand-alone software which has been replaced by online systems and is no longer available.

By far the most important priority for clearing is to protect water source areas (i.e. high water runoff areas) which carries 80% (0.8 out of 1) of the total weight compared with biodiversity at 20%. Under water sources the top priority goes to clearing the parts of the upper catchment that produce the most flow into the rivers and the dam, followed by the riparian invasions between the dam wall and the new abstraction weir. Riparian invasions are important to clear even though they occupy a small proportion of the catchment, because the invaders use more water per ha than upland invaders (Dzikiti et al., 2016; Le Maitre et al., 2015), even if they are the same species and age (Dzikiti et al., 2013; Everson et al., 2014).

Under biodiversity, the top priority goes to maintaining the desired fire regime, particularly the recurrence interval between fires (Van Wilgen et al., 2011; Wilgen and Forsyth, 2008), while using fire effectively for IAP control. This is important because pines and hakeas do not have long-lived seedbanks, which means that they can be controlled by felling or ring-barking to kill the adult trees and waiting a year for hakea, or 2-4 years for pines, before carrying out a planned fire. The fire then kills all or virtually all the young plants so that only a low level of maintenance is needed to ensure that the area is kept cleared (Kruger, 1977; Wilgen, 2012). The next priority is to clear the riparian systems and the final one is to protect threatened ecosystems, including conservation features such as Critical Biodiversity Areas (Pool-Stanvliet et al., 2017).

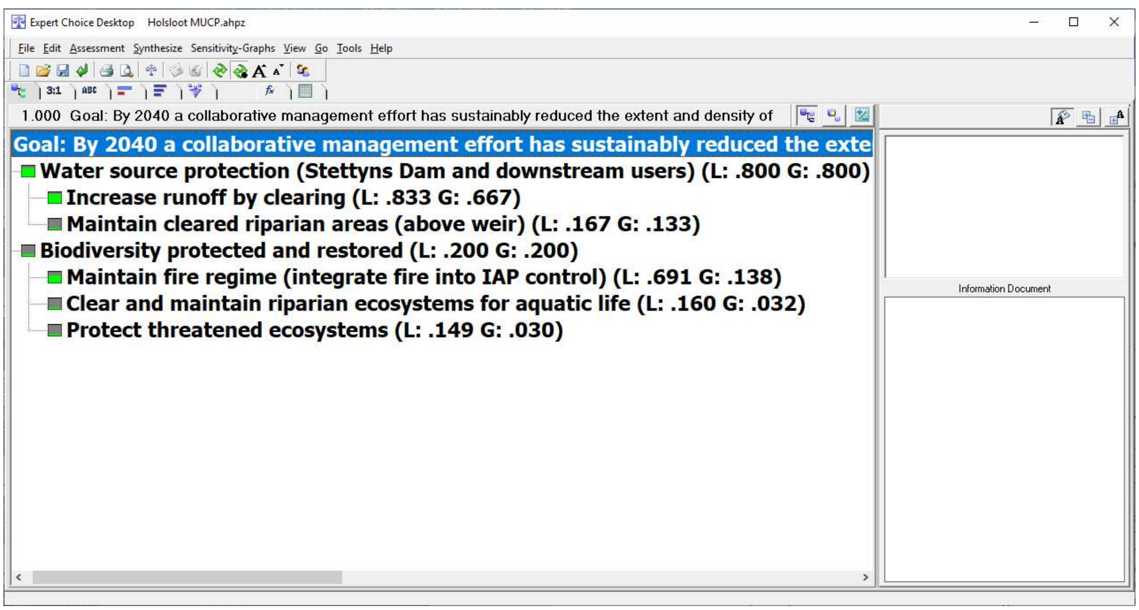

Figure 1: The AHP model developed for prioritising management units within the Holsloot catchment, showing the criteria and sub-criteria. G: = the relative importance or contribution of the criterion or sub-criterion to the whole model (scaled from 0 to 1); L: = the local contribution i.e. at that level in the hierarchy (scaled from 0-1).

4.3 IDENTIFICATION AND SELECTION OF DATASETS TO USE FOR THE CRITERIA AND SUB-CRITERIA

The first set of sub-criteria in the model (Figure 1) relate to the prioritisation of areas that are important for water source protection and increasing water quantity and for protection of aquatic ecosystems. These were represented by datasets on the mean annual runoff and buffered rivers (Table 1). Fire regime information was derived from datasets on the most recent fires (burnt areas) detected by remote sensing and mapped by CapeNature. Conservation planning priority areas and threatened ecosystems were taken from CapeNature's spatial biodiversity datasets.

Table 1: The criteria or sub-criteria and the datasets used to derive the necessary values

Criterion or sub-criterion	**Datasets used to generate the priorities with a brief description of the calculations**
Water source protection: mean annual runoff (mm)	Mean annual runoff dataset as used for the surface water Strategic Water Source Areas (Le Maitre et al., 2018; Nel et al., 2017) bilinearly interpolated to a grid of 250x250 m to align with the grid used for the National Invasive Alien Plant Survey (Kotzé et al., 2010). Calculated per compartment using the *ArcGIS* version 10, Spatial Analyst zonal statistics tool. Areas with the greatest MAR get the highest priority (Figure 2).
Riparian areas	1: 50000 river lines from the National Geo-spatial Information (Department of Rural Development and Land Reform) topographic maps. River reaches greater than 3rd order buffered by 50 m on each side to define riparian areas and identify riparian compartments between the dam and the weir (Figure 3). Clearing of riparian compartments given a higher priority than non-riparian ones for water quantity (riparian invaders use more water than on-riparian invaders) and for aquatic biodiversity.
Maintain fire regime	Current vegetation age derived from: (a) CapeNature's All Fires coverage for 2018 -19 for veld age for their Protected and Mountain Catchment Areas (available from the Biodiversity GIS https://www.sanbi.org/link/bgis-biodiversity-gis/); and (b) MODIS burnt area dataset converted to the days since the last fire for areas not included in the CapeNature dataset (data extracted from the Advanced Fire Information System database housed at the CSIR). The area-weighted mean post-fire age was calculated for each compartment (Figure 4). Top priority is given to clearing areas approaching an ecologically acceptable age for burning or older than that. This has been done so that clearing can be followed-up by appropriate use of prescribed fires.
Threatened ecosystems and biodiversity conservation priorities	We used two sources of information. Cape Nature's Biodiversity Spatial Plan Handbook (Pool-Stanvliet et al., 2017) datasets on (a) vegetation type threat status; and (b) Critical Biodiversity Areas (CBAs) type 1 and 2, and Ecological Support Areas 1 and 2 (downloaded from the B-GIS https://www.sanbi.org/link/bgis-biodiversity-gis/). Much of the catchment is in a CapeNature Reserve and does not have CBSs and ESAs, but the reserve does include threatened vegetation types. We used the vegetation status for the prioritisation (Figure 5).

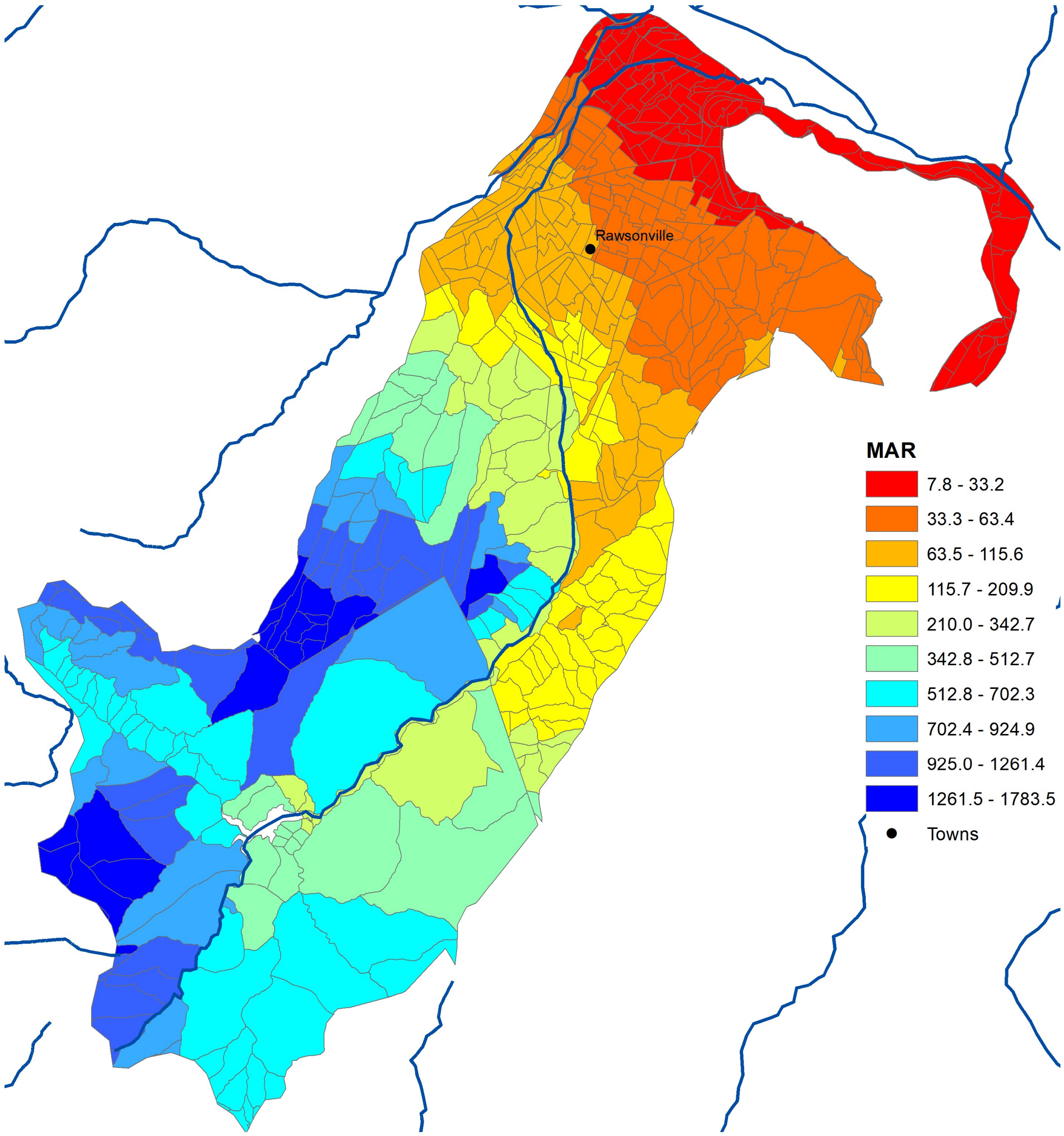

Figure 2: Mean annual runoff per compartment (mm/year). See Table 1 for more details of source data and processing. The compartments were derived from CapeNature mini-compartments and Natural Resource Management programmes dataset being generated for all quaternary catchments. For more information, see Table 2.

This map shows that the highest runoff occurs on the peaks and slopes in the south-western and western part of the catchment. The eastern side falls into a rain shadow area because the winter rainfall mainly comes from the north-west and south-west.

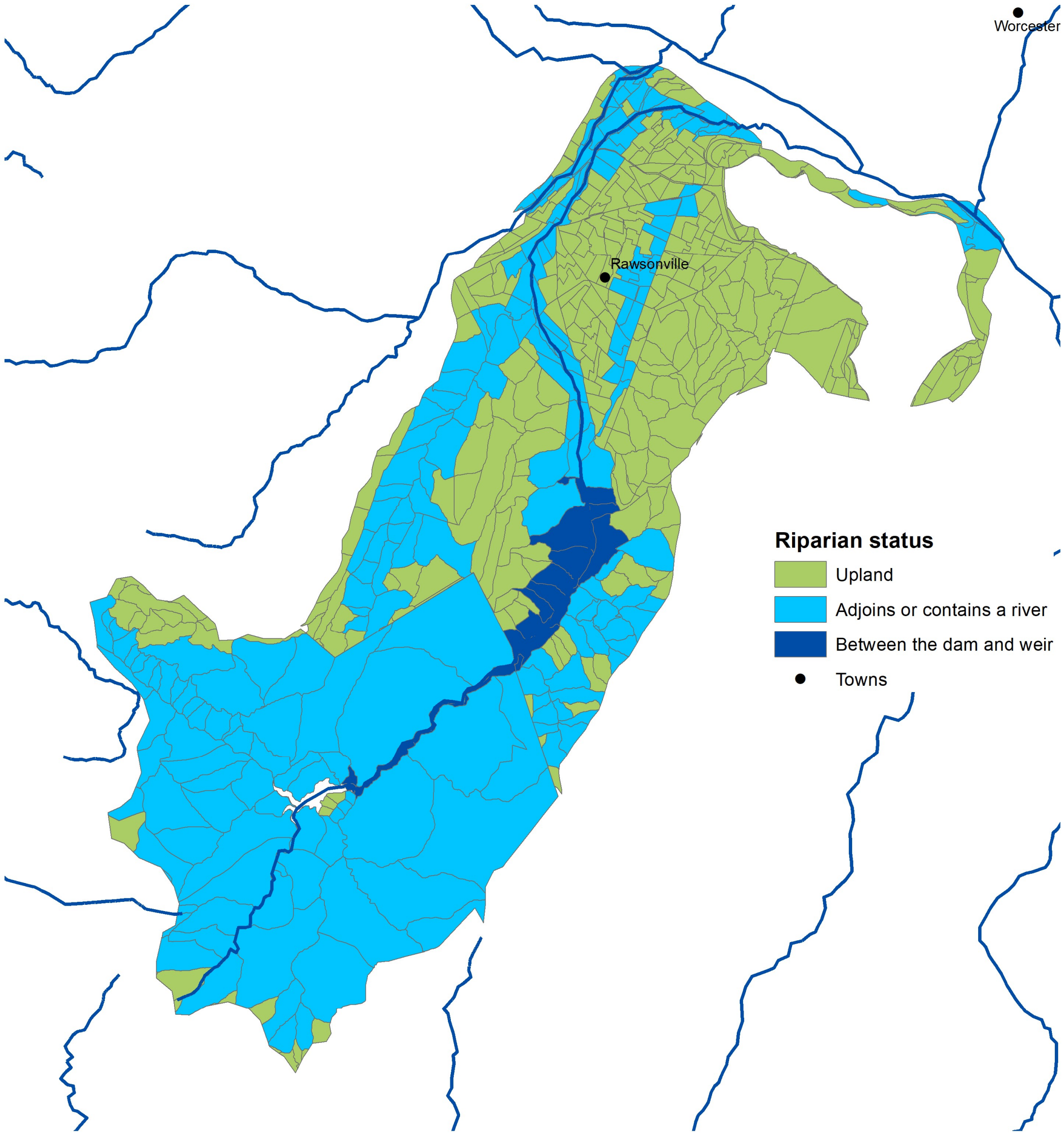

Figure 3: Compartments identified as riparian based on the 3rd order streams and rivers from the river network produced for the 1:50 000 topographic map series. For more information, see Table 1.

The map shows a very large number of the catchments being highlighted as riparian in the sense of adjoining or containing a reach of a stream or river. We assessed the potential for reducing the proportion of riparian compartments using the 1:500 000 rivers from the national river database (van Deventer et al., 2020; Van Deventer et al., 2018), but this dataset did not include important tributaries of the Holsloot. The riparian catchments between the new diversion weir and the dam wall was specifically chosen as a priority in the workshop (Figure 1).

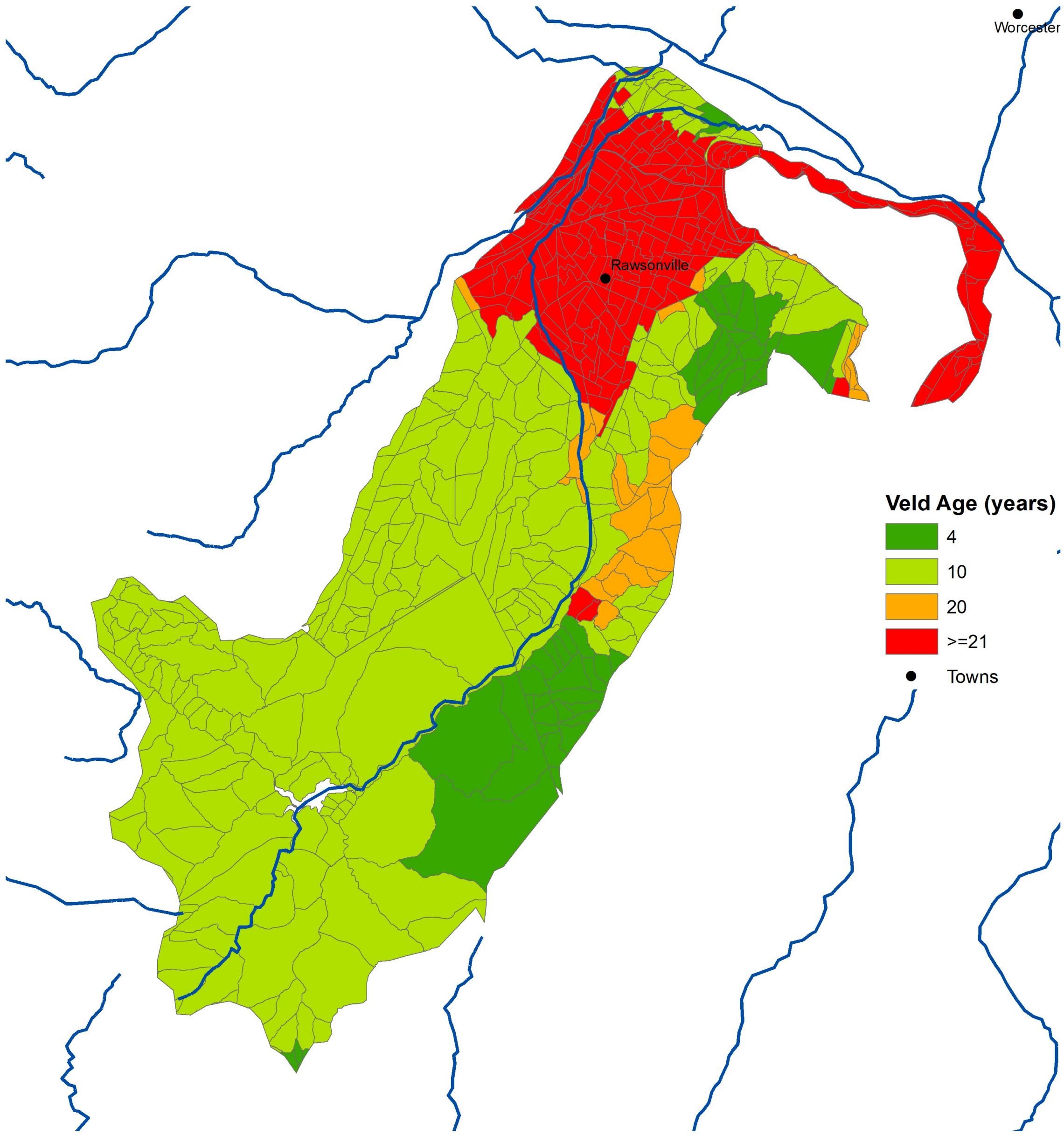

Figure 4: Mean post-fire veld age for each compartment based on records of historical fires. For more information, see Table 1. There are no records of fires in most of the farmed areas so we have assumed that they are at least 21 years old.

Much of the catchment was burnt in a large fire 10 years ago and is coming up for prescribed burning. Large areas of the catchment are invaded by pines and hakea species which can be effectively controlled by felling or ring-barking and then burning the treated areas. This is a window of opportunity that should be used. Some of these areas also have invasions of *Acacia* species which will need follow up after fires. The farmed area is of an unknown age because we have no records of fires there, either because there were none or because the size of the natural remnants was too small for the fires to be detected by remote sensing. Much of this area is invaded by *Acacia* and *Eucalyptus* species which are more effectively treated using other methods, including ring-barking and herbicides.

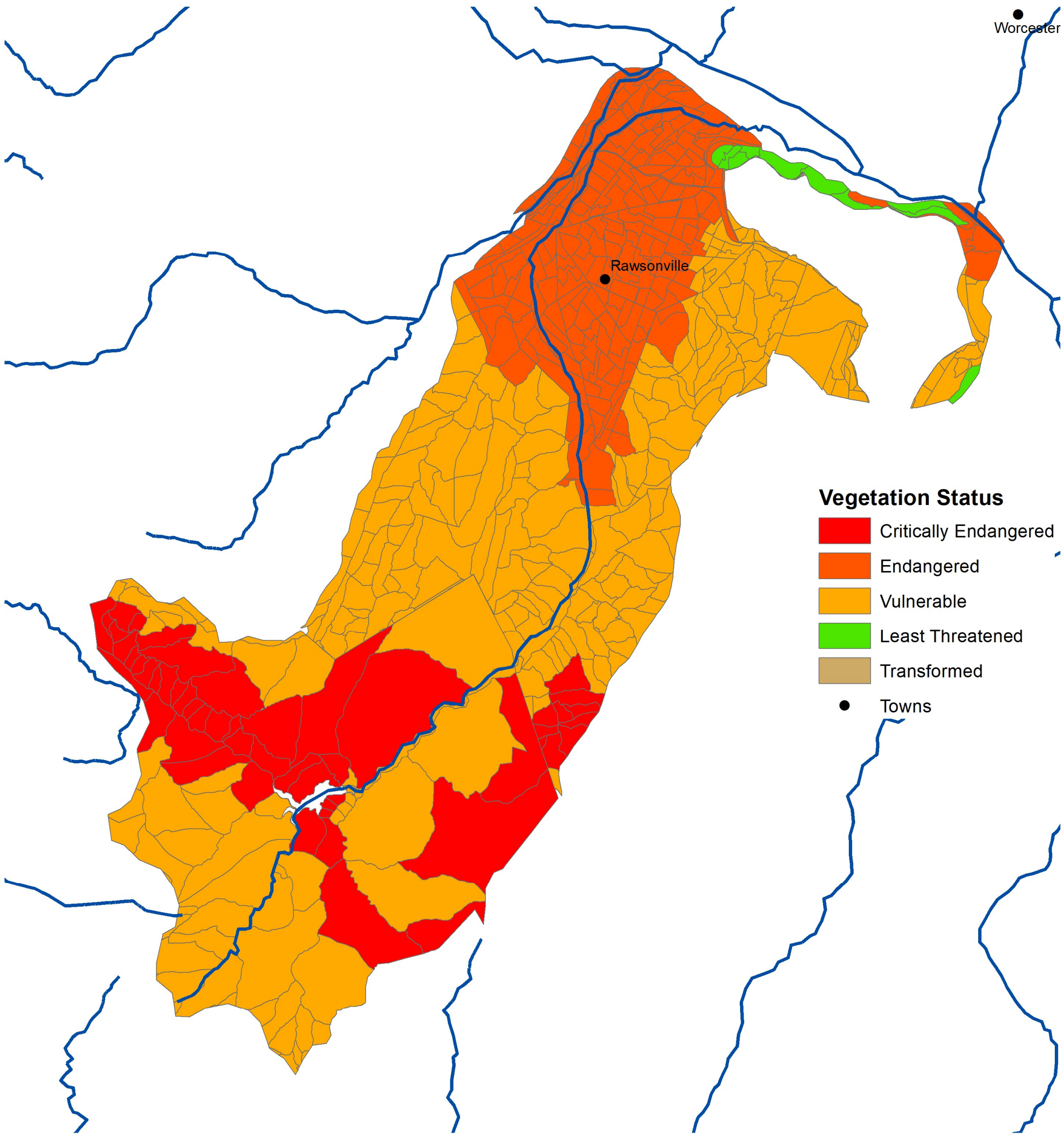

Figure 5: The vegetation status defined for each compartment based on the threat status given to the different vegetation types in the Biodiversity Spatial Plan (Pool-Stanvliet et al., 2017). *For more information, see Table 1.*

Virtually all of the compartments contained a threatened vegetation type with most falling within the vulnerable Hawequa Mountain Fynbos as described in section 4.1. The critically endangered Elgin Shale Fynbos, in the southern portion of the catchment, and the Endangered Breede River Alluvium Fynbos in the north make up the rest.

4.4 Datasets used in the creation of the compartments, mapped invaded units and NBALs

The MUCP tool requires datasets for the management units (compartments), all known or mapped invasions (MIUs) and treated areas (i.e. NBALs).

Table 2 The basic spatial datasets required by the MUCP tool, data sources and processing.

Spatial dataset & attributes	Source datasets and data processing
Compartments	CapeNature's mini-compartments (supplied by CapeNature) combined with a compartment dataset developed for Natural Resource Management programmes (Department of Forestry, Fisheries and Environment) for use for planning, including the MUCP tool. The compartments take account of natural features as well as administrative boundaries (cadastres); compartments were identified as riparian (see Table 1) to create riparian and non-riparian compartments.
Mapped Invaded Units	All the mapped invasion data that could be used, including the attribute data in CapeNature's mini-compartment dataset. This information was combined with the NBAL data (see below) to give as complete a coverage as possible (i.e. all treated and untreated areas). The datasets compiled for the Socio-Economic Benefits of Ecological Infrastructure (SEBEI) project were also examined but only included a density estimate. No species-level data were provided so we only used this data for those compartments where moderate to dense pines stands occur in the southern part of the catchment.
Treated invaded units (NBALs)	Data for treated areas supplied by Andrew Wannenburgh (NRM programmes) from the WIMS database; the records for the most recent treatment contract were taken as representing the current state. NBALs that had not been followed-up for 5 years or more were considered untreated.

4.5 PRIORITIES ESTIMATED USING THE MULTI-CRITERIA (AHP) MODEL

The values for each compartment for each of the variables, which represents each of the criteria and sub-criteria in the model, were extracted and compiled in a spreadsheet. The export Grid option in the AHP software was used to create a spreadsheet template into which the values for each compartment (alternative) could be copied. The values from this prioritisation dataset were copied to the correct columns in the template spreadsheet. The completed template was then imported into the AHP grid and loaded into the software for processing. The resulting priorities are shown below.

The priorities shown here will not be identical to those generated by the MUCP tool, because the way they estimate priorities is not exactly the same. However, there will still be a general correspondence and alignment between those generated by these two software packages. It is important to note that the priorities assigned by the model are directly influenced by the weights given to the compartments for the criteria and sub-criteria in the model. If those weights are changed, then the priorities will shift. We have illustrated this by including maps showing the priorities for the water source protection and restoration criteria as well.

The priorities generated for the goal are strongly influenced by the high weight given to the water source protection criteria of 80% (Figure 1). The greatest mean annual runoff is generated in the north-western and western side of the catchment and this also where the top priorities for the goal are located (Figure 6). There is also an area of high runoff in the middle of the catchment, north of the Holsloot River. The lower section of the catchment generates relatively low runoff and so gets the lowest priority for clearing. The exception to this overall pattern is the section of river between the Stettynskloof dam and the new weir, where the priority has been increased by the inclusion of a criterion that recognises the importance of maintaining the existing clearing in the riparian compartments in this area.

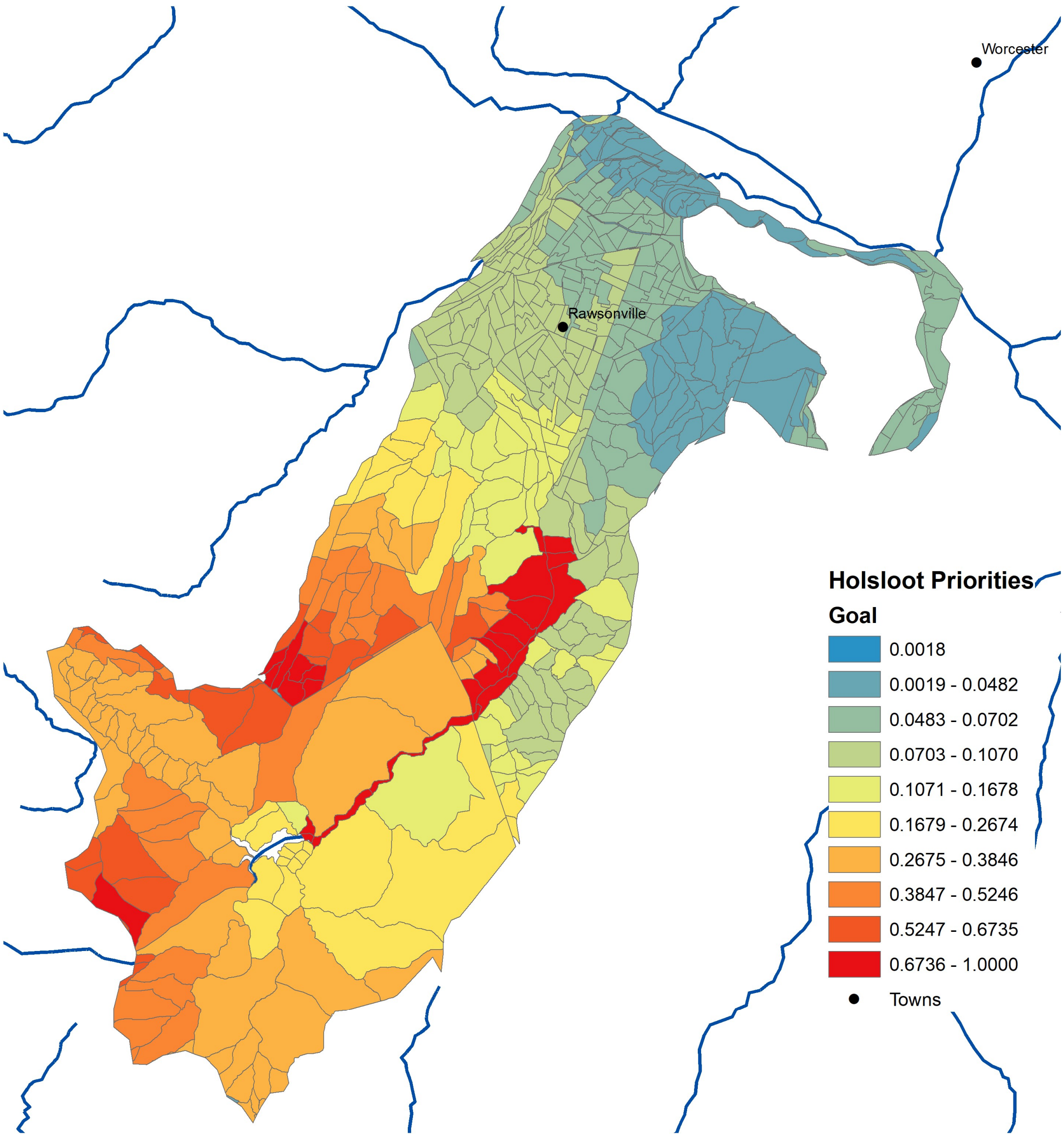

Figure 6: The Holsloot catchment showing the priority values for each management compartment based on the overall goal as defined in AHP model (Figure 1), and the values for each compartment of each of the variables in the model.

There is an important point that needs to be noted, namely that it is important to maintain a clear distinction between the priority given to a compartment and the resources (including budget) required to treat the invasions in it, if any. The fact that a compartment is the top priority does not mean that it has to receive all the resources. In fact, it may not have any invasions at all, and simply requires regular inspections and, thus, a tiny budget to ensure that it stays that way. Even where it does have invasions, they may only require a small proportion of the resources for effective treatment. The remaining resources can be allocated to the next highest priority compartments according to their treatment requirements. That said, it is vital that the top priority catchment should receive the resources required for effective control before resources are allocated elsewhere.

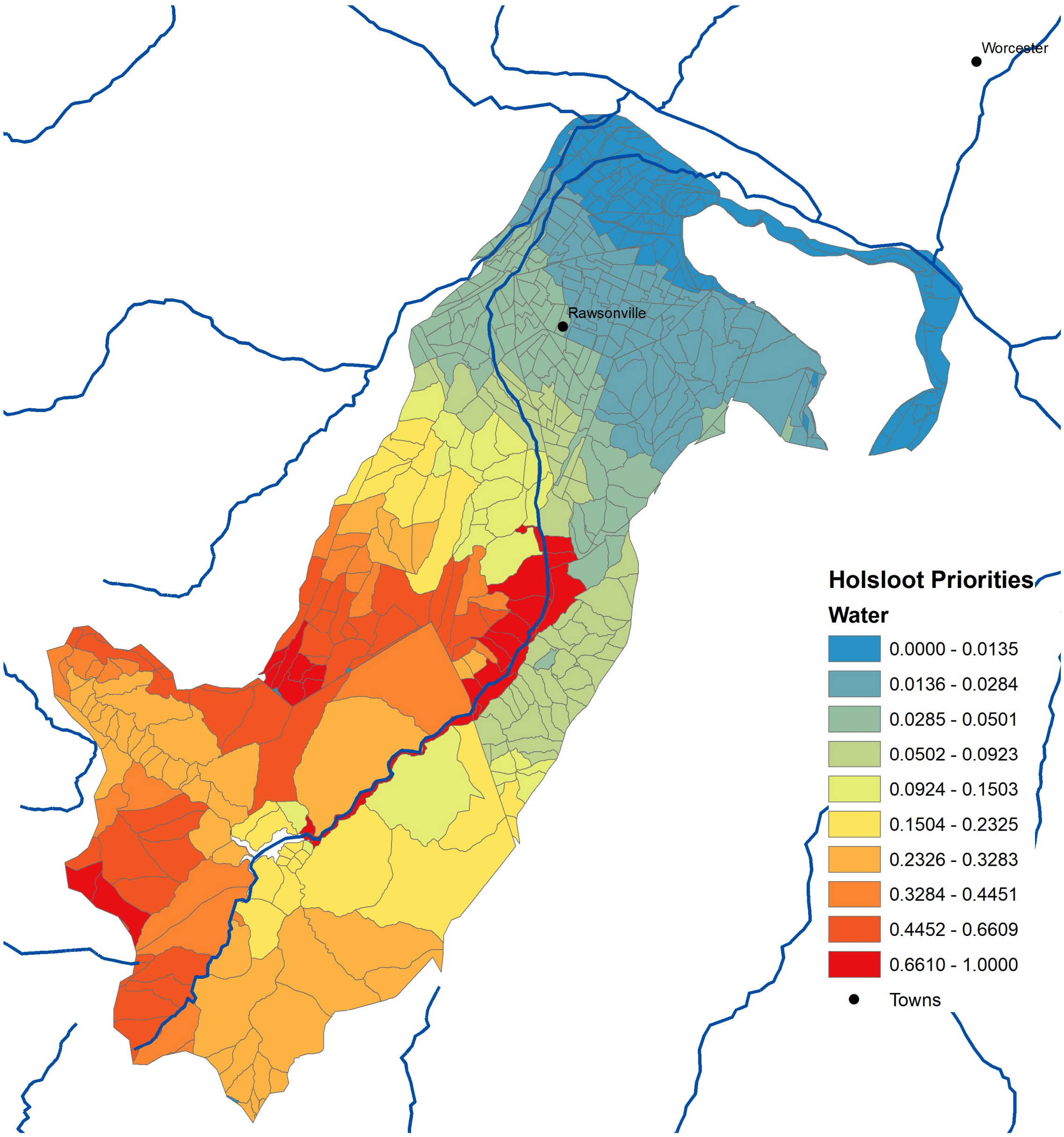

Figure 7: The Holsloot catchment showing the priority values for each management compartment for the water source protection criteria as defined in AHP model (Figure 1,) and the values for each compartment of each of the variables in the model.

The priorities for the criterion of water source protection (Figure 1) on their own are virtually identical in their distribution to those for the goal because the water source protection criteria have such a high importance (weight) in the model (Figure 7). In the long run, the greatest MAR reductions due to alien plant invasions within this catchment are likely to be due to the extensive, and increasingly dense, pine invasions in the southern part of the catchment. These are only given a moderate priority both for the goal and water source protection. This is because the MAR generated in this part of the catchment is lower than the areas given a higher priority. As noted above, the compartments given a higher priority for water source protection may only require a relatively small proportion of the resources, making resources available to treat the more densely invaded areas even where the MAR gains would be less.

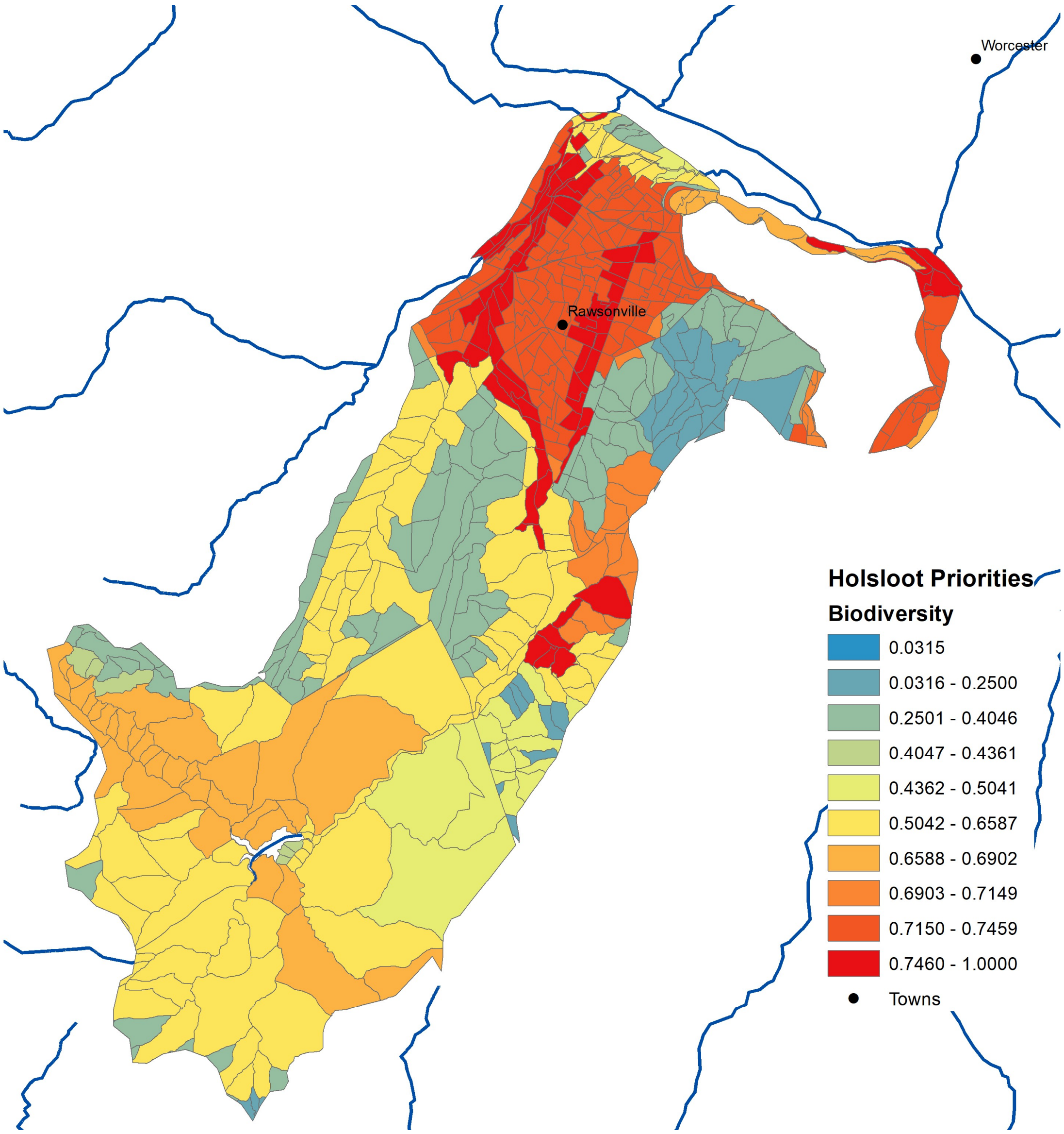

Figure 8: The Holsloot catchment showing the priority values for each management compartment for the biodiversity protection criteria as defined in AHP model (Figure 1) and the values for each compartment of each of the variables in the model.

The priorities for biodiversity protection and restoration are the reverse of those for the goal and for water source protection. This is because the biodiversity priorities are driven by the criteria that focus on the potential conservation value of protecting threatened vegetation types and conservation asset connectivity. The high priorities are, therefore, all for compartments containing (near-)natural remnants of these vegetation types located in within the intensively farmed areas near the Breede River. Many of these remnants are already being given protection through stewardship and other conservation agreements with the land-owners (Francis Steyn personal communication, March 2020).

Most of the recent alien plant clearing investments have been in this lower part of the catchment so, although adequate investment in follow-up is essential to ensure that the gains are maintained, only a relatively small proportion of the resources may need to be invested in the treated areas. The bulk of the resources could be invested in untreated areas shown as having a high priority for the goal. The farmers may also wish to continue investing their own resources, or only require some costs subsidisation, to continue clearing in the areas highlighted for restoration. This would allow other resources to be freed up to address the higher priorities for the goal and for water source protection.

4.6 OUTPUTS OF THE MUCP SYSTEM: PRIORITIES AND RESOURCE REQUIREMENTS

The MUCP system generates a number of outputs, most of which are best viewed using the facilities in the system (e.g. the maps generated by the Visualisation section) or by exporting the datasets to spreadsheets (e.g. the treatment schedules and budgets).

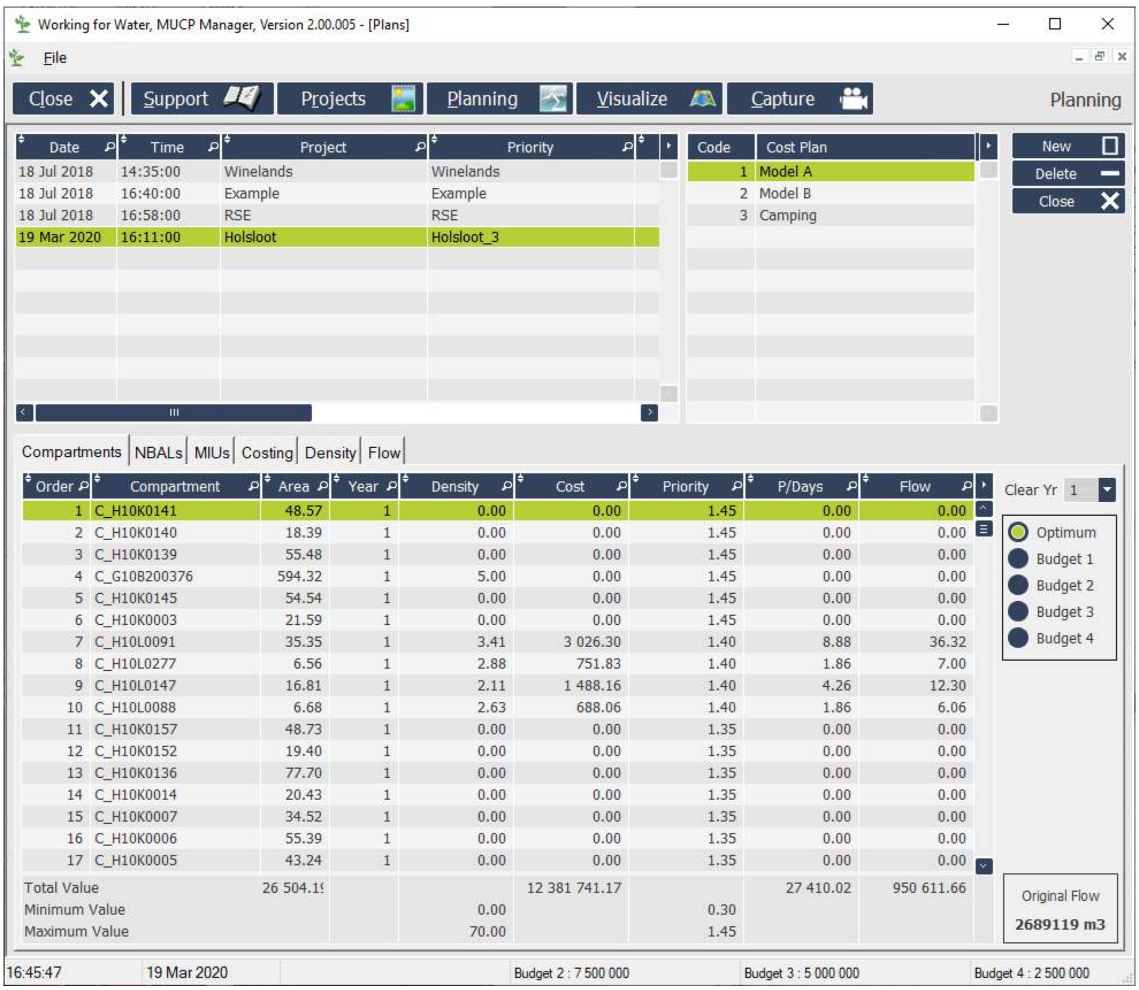

Figure 9: A part of the planned treatment schedule showing cost information for each compartment for each of the next 20 years for the Optimum budget. The optimal budget is generated by the system to be sufficient to treat the entire catchment in as short a time as possible. For more information, see the text.

This screen capture from the system (Figure 9) shows the information displayed for a particular cost scenario (Optimimum budget) for the Holsloot using the global priority weights as generated in the workshop (Figure 1) converted into a priority model (Holsloot_3, Figure 9 upper pane). The compartment tab has been selected and the lower pane displays the unique Compartment code, its area, the treatment year, the density of the invasions, the planned budget, priority, person days and the increase in runoff that could be expected in m³/year. The data also show that three of the top priority compartments have no invasions, illustrating the importance of distinguishing between the priority scores, and the resource allocations required for the treatment. The summaries at the bottom of the lower pane show that the optimal budget in year one would be about R12.4 million using the cost models indicated at the upper right of the top pane and their allocation to different compartments.

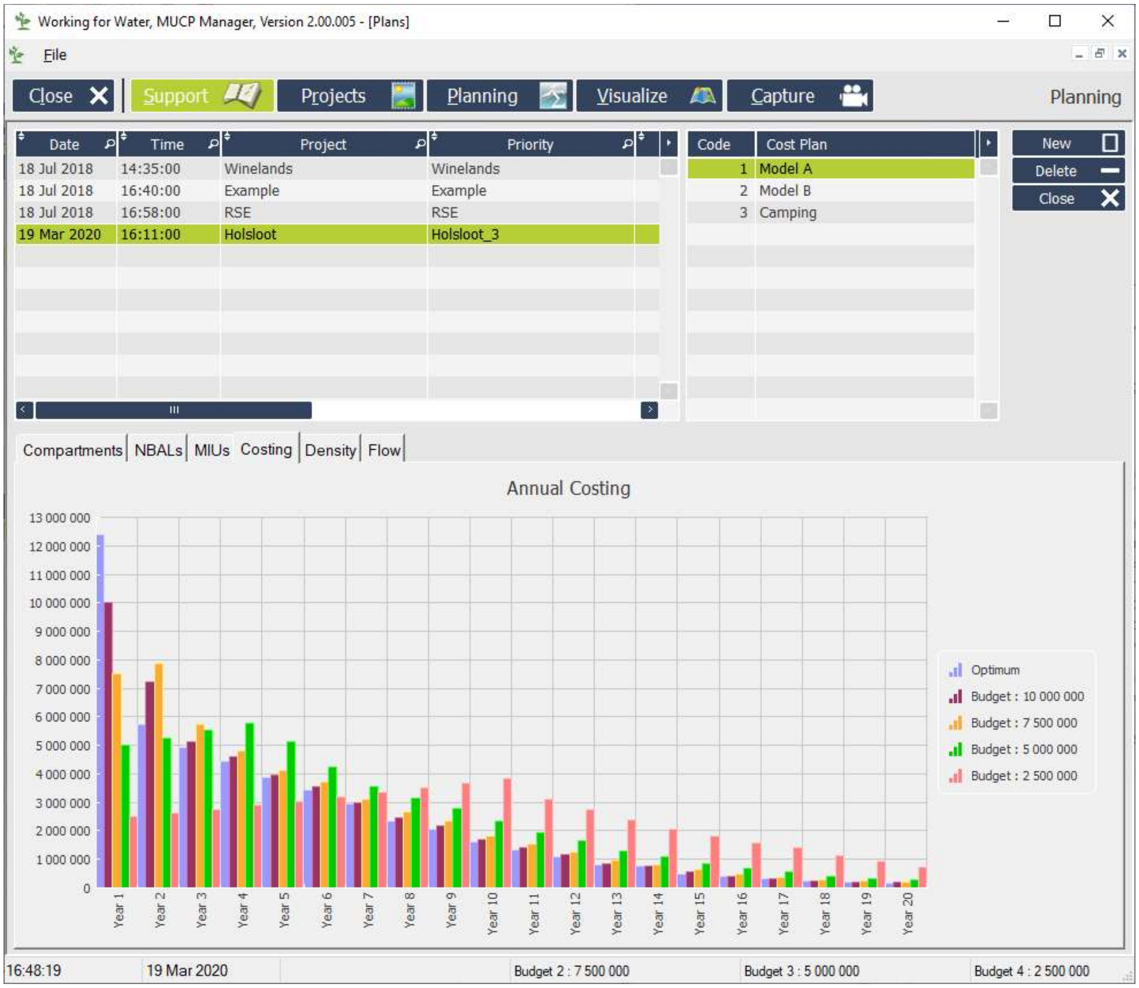

Figure 10: The information displayed when the Costing tab is selected showing the planned annual budgets for different budget ceilings over the 20 year planning horizon used by the MUCP system. The budgets all escalate at 6% per year to allow for inflation.

The Costing or planned expenditure tab displays a timeline of the annual expenditure that will be required to reduce the densities of all the invasions in the catchment to maintenance levels. The Optimal budget is automatically calculated by the system and is included to illustrate the funding required to reduce invasions in the minimum amount of time. The four budgets that the user sets are all sufficient to get the invasions down to low levels within 20 years. The lowest budget of R2.5 million only really starts to reduce the resources requires from year 11. Densities also increase over time in areas that are not cleared, which increases the costs when these areas do get scheduled for treatment.

The timeline of the decrease in the mean density of the invasions in the catchment (Figure 11) shows that the budget of R5.0 million will reduce the densities to the same levels as the larger budgets, but it will take more than 15 years to achieve this. The lowest budget of R2.5 million per annum would not be sufficient to clear the catchment to low densities throughout within the 20-year time frame.

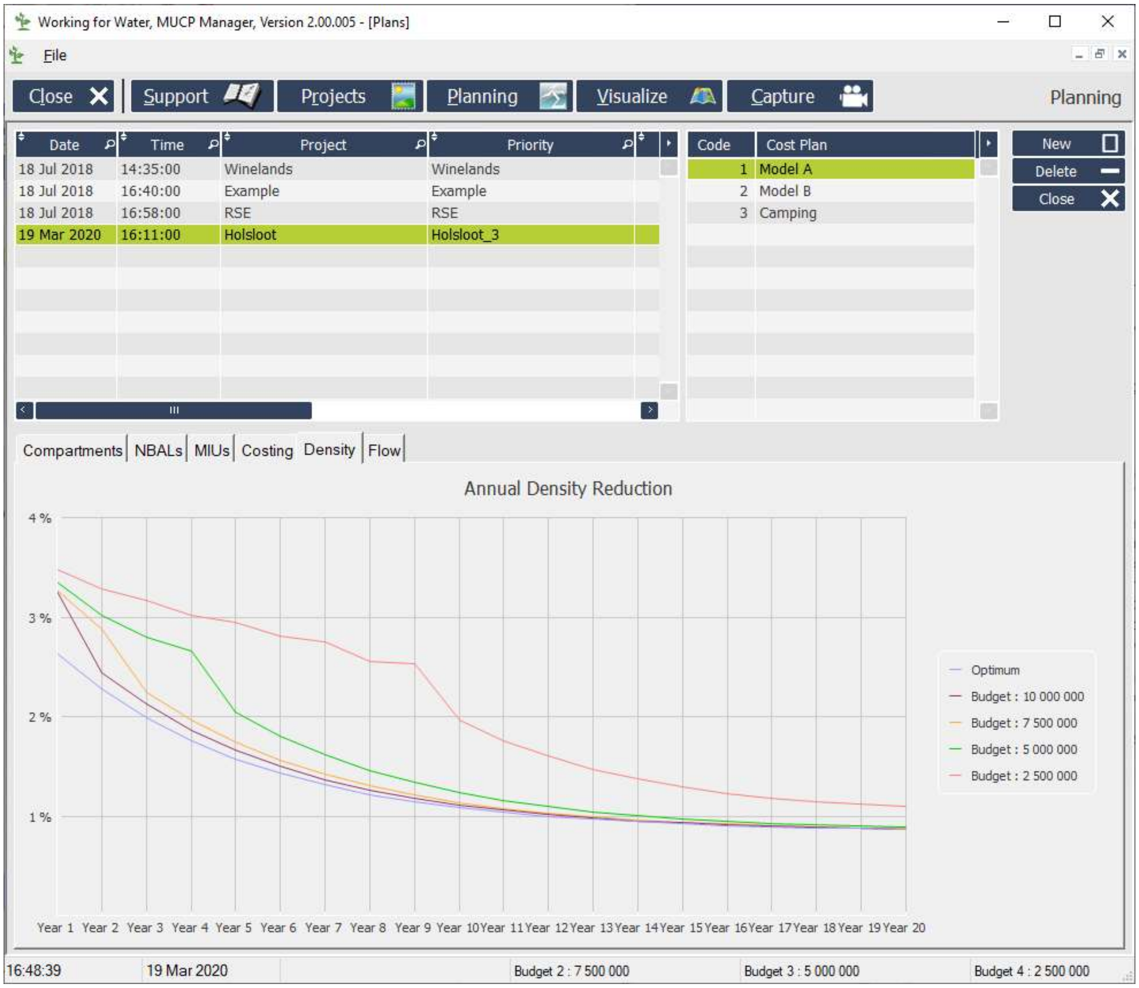

Figure 11: The planned rate of reduction in the density of the invasions over 20-year planning horizon used by the MUCP system.

The decline in the volume of water used by the invasions (Figure 12), over and above that used by the fynbos they are replacing, is particularly high in the first year, but the rate of decline decreases in the later years. The R5.0 million budget results in a decrease that is much less than that of the larger budgets till year 4 and then begins to catch up. The lowest budgets does quite well in year 1 but slows significantly and lags all the larger budgets for the rest of the 20-year time-frame.

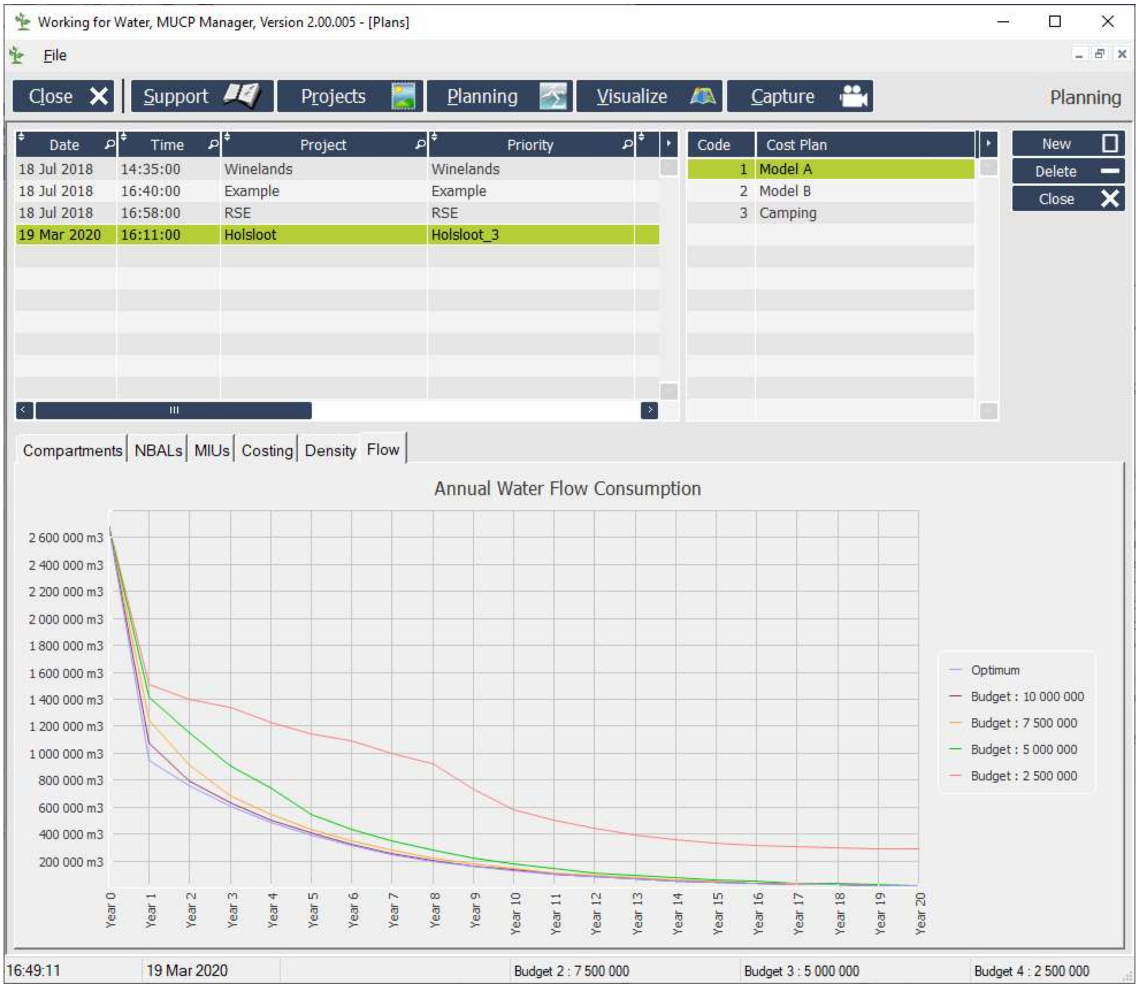

Figure 12: The projected decline in the annual water flow consumption (i.e. the amount of water used each year by the invading plant species) for each planned budget.

The multi-criteria model and the MUCP system do not calculate their priorities in the same way from the weight so the priorities given to the different compartments are not the same, but they show similar spatial patterns. The priorities as calculated by the system (Figure 13) are somewhat similar to those generated by the multi-criteria model (Figure 6) but there are also some clear differences. The highest priority is given to a set of compartments in the south-eastern part of the catchment and a small compartment in the farmed area on the Breede River (which is uninvaded). The next set of priorities is given to the high runoff areas in the southern part of the catchment. The weights for biodiversity and riparian ecosystem protection are influencing the results more than is the case in the multi-criteria AHP model. It is important to emphasise that these are the provisional results and will be evaluated with the workshop participants to refine them.

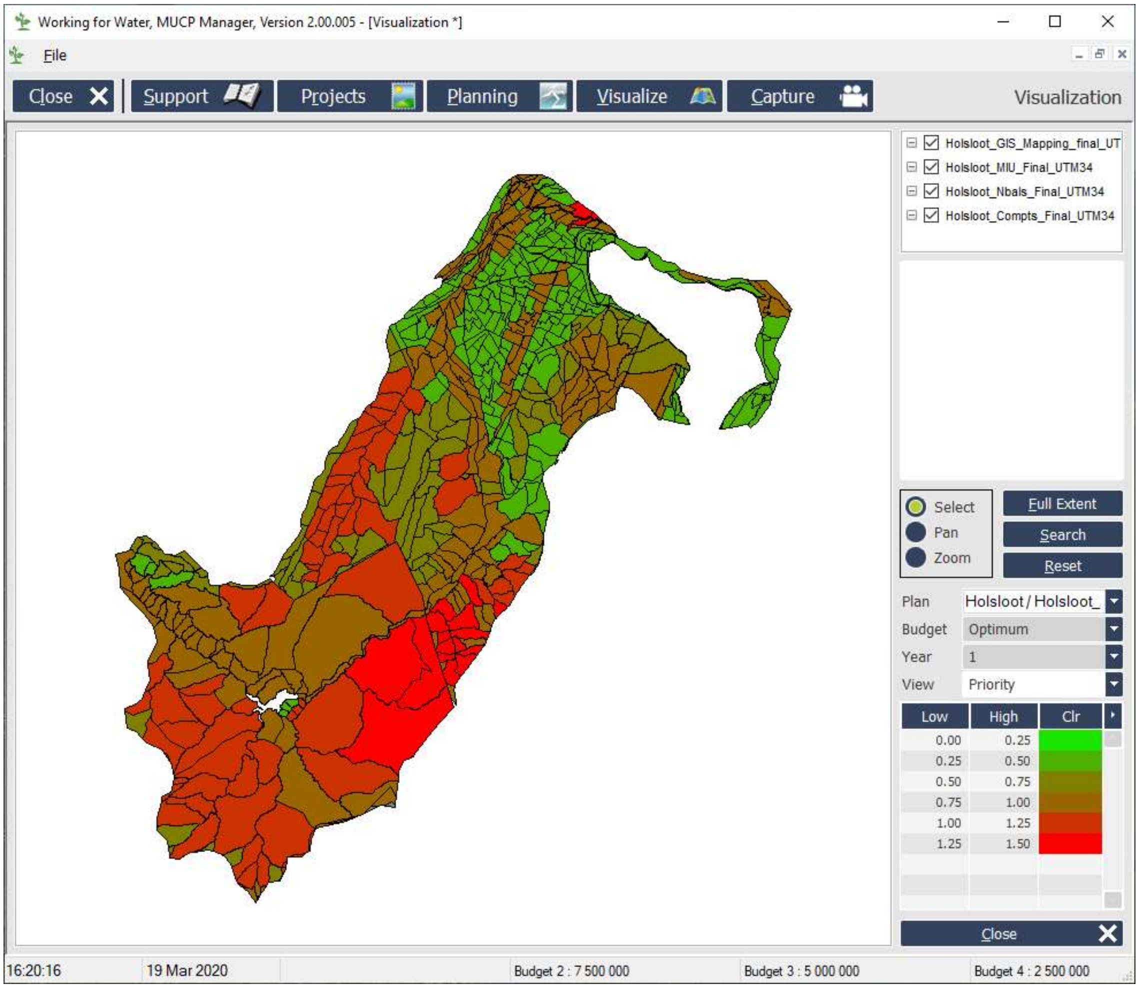

Figure 13: The priority calculated for each compartment by the MUCP system based on the global weights given to the different criteria in the multi-criteria model developed in the workshop.

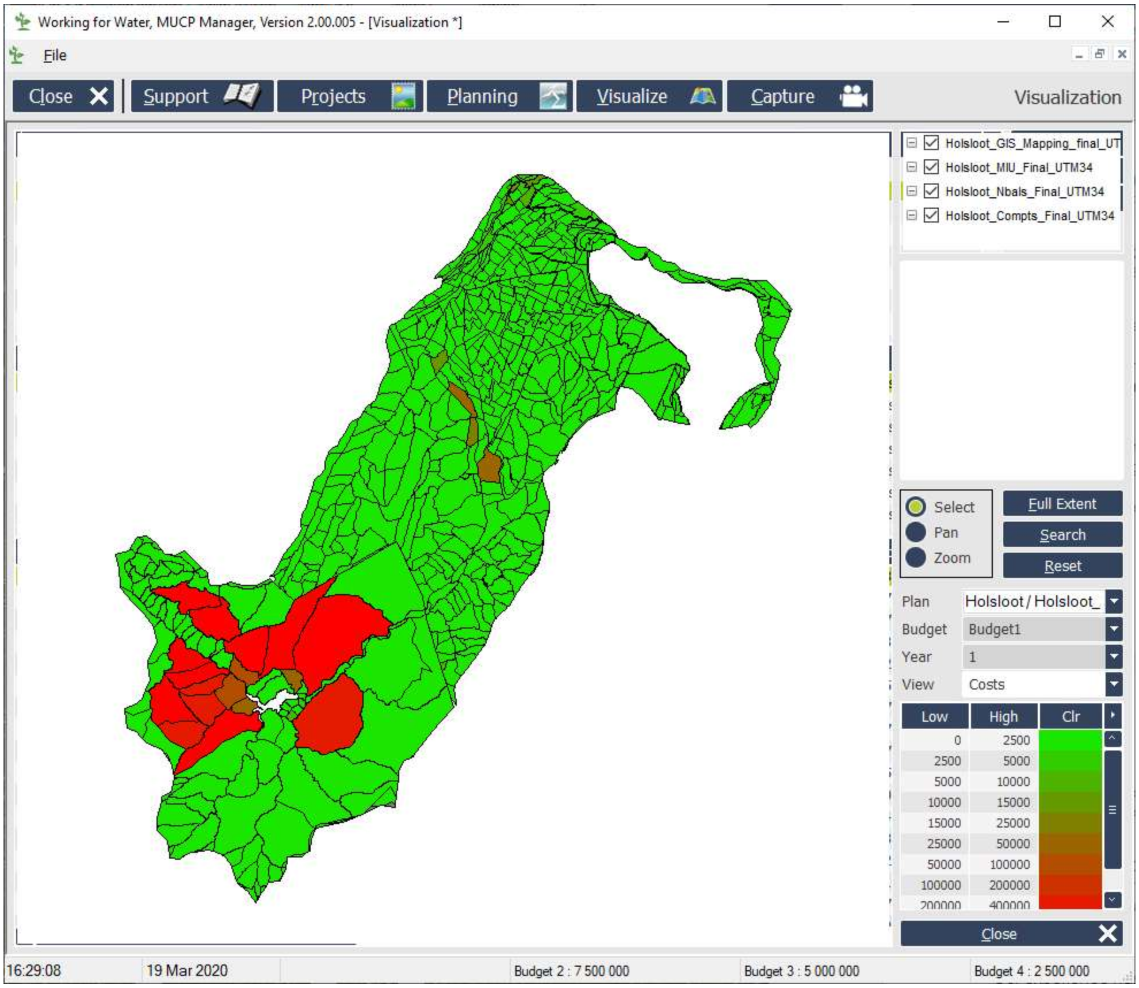

Figure 14: The budgets allocations for the different compartments in the Holsloot catchment for year 1 and Budget 1 of a maximum of R10 million (Figure 10).

A comparison of the planned budget allocations to compartments for the largest annual budget of R10 million (Figure 14) and the lowest annual budget of R2.5 million (Figure 15) shows that a number of compartments across the catchment will not be treated in year one on the lower budget.

This section illustrates <u>one</u> outcome of the treatment programme model based the set of priorities, the potential budgets, the costing models used for the treatments and the treatment norms. The MUCP system also allows users to adjust factors that change the resources required for control. For example, the annual rate of increase in density can be set for each species. It has a large effect because invasions in the untreated compartments continually increase in density, resulting in increasing treatment costs. The users can also specify the reductions in density following either initial clearing or follow-ups on a given species. If the reductions are small, the density for the follow-ups will be higher and they will have to allocate more resources per year to those follow-up treatments. This will increase the annual budget or reducing the area that can be treated. If the reduction is large, then densities and resource requirements will decrease more rapidly and a greater area can be treated. We have used the default values for this modelling, but the actual values can be set by the participants in the planning exercise.

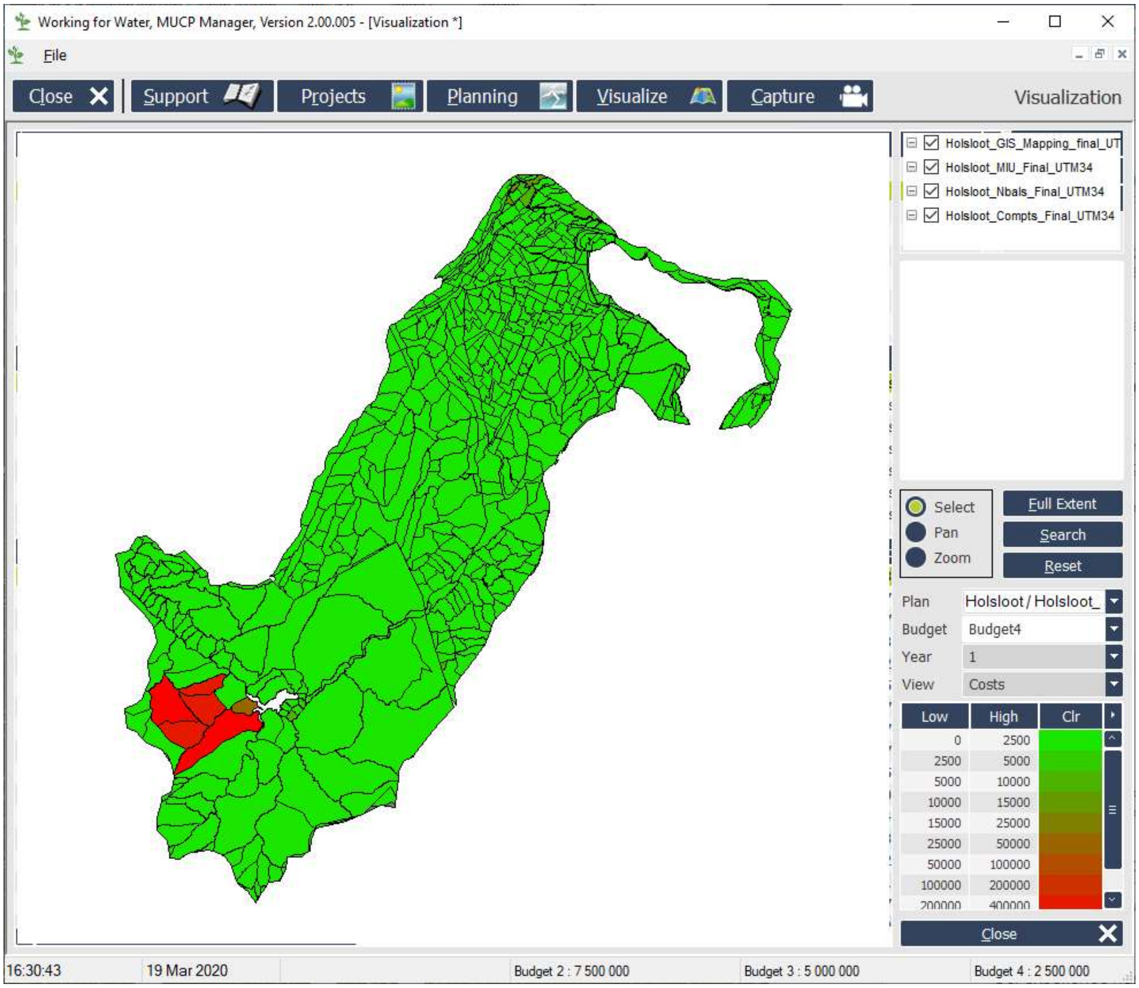

Figure 15: The budgets allocations for the different compartments in the Holsloot catchment for year 1 and Budget 4 of a maximum of R2.5 million per year.

5 KARATARA

5.1 CATCHMENT DESCRIPTION

The Karatara catchment is located to the north of the town of Sedgefield. The Karatara River has its source in the Outeniqua Mountains and drains into the north-eastern part of Swartvlei Lake. The payments for ecosystem services (PES) assessment for this catchment (DEA&DP, 2018a) used the quinary (5th order) catchments that were developed for the National Freshwater Ecosystem Priority Areas study (Nel et al., 2011). The boundaries differ markedly from those defined for the National Water Resource Assessments at the quaternary (4th order) catchment level (Bailey and Pitman, 2015) and those used by DEA-NRM (working for Water) in their planning. There are five quinary catchments which cover an area of 18 397 ha, and their boundaries include portions of quaternary catchments K40D and K40E, and the whole of K40C. Most of the runoff is provided by catchment K40C which is 9 956 ha in extent and has a mean annual runoff of 243 mm. The coastal portion of the PES study's quinary catchments includes the eastern part of Swartvlei Lake and Groenvlei Lake, and extends from near Pinedew in the west to include a portion of the Goukamma Nature Reserve in the east. To align the plan with the Working for Water approach of using quaternary catchments, we have used the two quaternaries: K40C and K40D in the prioritisation and in the MUCP tool.

A weir in the Karatara River is the primary source of water for the towns of Sedgefield and Karatara, a forestry settlement inland on the coastal plateau. An extended drought resulted in the installation and operation of a desalination plant for Sedgefield in 2015. This plant, apparently, is not currently in use because the relatively good rains since the drought have enabled Sedgefield to obtain sufficient water from the flows in the Karatara River. The town's water security currently is regarded as low compared with findings of the All towns study in 2011 that water security was high (DEA&DP, 2018b; DWS, 2014). This shift in status is a strong motivation for investment in invasive alien plant clearing in the Karatara catchment (K40C) to increase water security for the settlements in the catchment.

The vegetation in the upper part of the Karatara catchment is South Outeniqua Sandstone Fynbos, the middle catchment was a mixture of Garden Route Shale Fynbos and Southern Afrotemperate Forest, and the coastal portion of the catchment by Knysna Sand Fynbos and Southern Cape Dune Fynbos (Rebelo et al., 2006). A large portion of the middle and lower catchment has been transformed into commercial plantations, cultivated lands for dairy farming and for irrigated vegetable production, with urban areas located mainly around Swartvlei and on the coastal dunes, except for the Karatara settlement. There are extensive invasions of a wide range of species, mainly pines (*Pinus pinaster* and *P. radiata*) and *Hakea* species in the Karatara catchment, *Acacia mearnsii, A. longifolia, Paraserianthes lophantha,* and *A. melanoxylon* in the river floodplains and parts of the middle catchment, and *Acacia cyclops* in the dune systems. The annual flow reduction in catchment K40C in 2007 was estimated to be at least 8.4% (2.3 million m^3) and is projected to increase to 20.9% by 2032 (D.C. Le Maitre unpublished data). For K40D the corresponding values are 4.6 and 9.4%.

The mapped information on invasions is considered satisfactory for the CapeNature areas (Goukamma) but poor for the rest of the catchment which was last mapped in 2008 (Vromans et al., 2010). The 2008 mapped data were updated at desktop level by adjusting densities and ages in 2018 (Paul Buchholz personal communication March 2020). This is especially true of the recently burnt areas in the catchment where we have used our expert knowledge to update the 2018 invasion data. The result is that our confidence in the estimates of the resource requirements generated by the model is low.

5.2 WORKSHOP AND MODEL DEVELOPMENT

The workshop for the Karatara and Keurbooms catchments was held on the 21st of November in the Sedgefield Council Chambers in Sedgefield. The participants represented local municipalities, CapeNature, South African National Parks, agriculture and NGOs from the conservation sector (see Appendix 2 for the attendance list). The CSIR team welcomed those present, got them to introduce themselves, and then gave a presentation on the AHP approach and the MUCP tool and its requirements and outputs. The next step was to discuss and jointly define a goal for the management of the IAPs in the catchment that was SMART (Specific, Measurable, Assignable, Realistic and Time-bound). This process resulted in the following goal for the Karatara catchment:

By 2030 a collaborative and coordinated management effort has increased water production, established an acceptable fire regime, restored river and wetland systems, *biodiversity, while generating sustainable livelihoods and increasing resilience to climate change for all inhabitants*

After this we used the AHP modelling software to help generate a set of criteria and sub-criteria for spatially prioritising management actions aimed at reducing the impacts of invasions in the catchment. After intensive discussions, the participants came up with an AHP-based prioritisation model. It is similar to the one for the Holsloot with two high-level criteria: one prioritising IAP management to secure and enhance water production and the other on restoring functional landscapes that deliver enhanced suites of benefits from EI (Figure 16). In this case, water production carries two-thirds of the weight (0.667, 66.7%) and restoring functional landscapes 33.3%. Water production focuses on water quantity and water flow regulation, with water quantity recognising the importance of restoring both riparian and upland portions of the landscape. Restoration of wetlands, including river floodplains, is the focus for restoring water flow regulation, by enhancing dry season river flows (i.e. baseflow). Restoration would also help reduce the responsiveness of the catchment to larger and intense rainfall events (e.g. cut-off lows), reducing flooding and flood damage. Restoration focuses on re-instating an appropriate fire regime for the catchments, particularly the areas originally under fynbos, most of which have become significantly too old from an ecological perspective, and are now overgrown. The high fuel loads in the long-unburnt vegetation were a significant factor in increasing the difficulties of controlling the Knysna fires, one of which had its origin in this catchment (Forsyth et al., 2019; Frost et al., 2018).

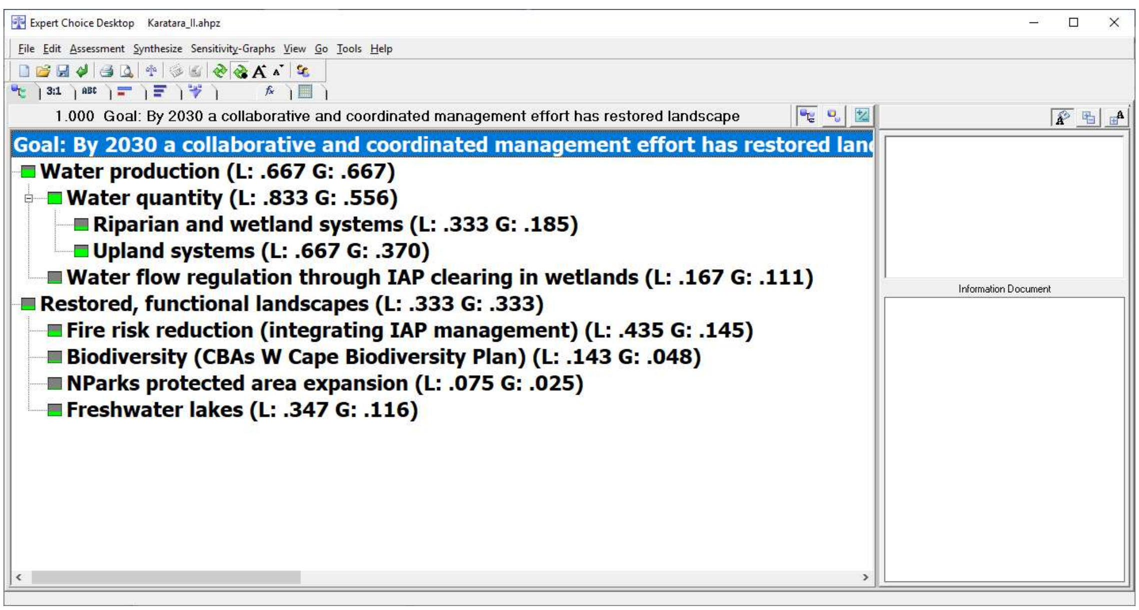

Figure 16: The AHP model developed for prioritising management units within the Karatara catchment, showing the criteria and sub-criteria. G: = the relative importance or contribution of the criterion or sub-criterion to the whole model (scaled from 0 to 1); L: = the local contribution i.e. at that level in the hierarchy (scaled from 0-1).

5.3 IDENTIFICATION AND SELECTION OF DATASETS TO USE FOR THE CRITERIA AND SUB-CRITERIA

The structure and criteria and sub-criteria used in this model (Figure 16) are very similar to those used for the Holsloot (Figure 1). The first set in the hierarchy is aimed at prioritising the areas that are important for water source protection and increasing water quantity and for protection of aquatic ecosystems. The runoff was interpolated from a dataset on the mean annual runoff and the estimated for each compartment (Tale 3). The compartments were divided into those that included riparian (buffered) or wetland areas and the upland areas. The runoff gains from clearing upland areas are typically lower per unit area than those from riparian or wetland areas, but the upland areas are typically much more extensive, and clearing generally results in a greater increase in overall MAR. The last set focuses on protecting biodiversity. Fire regime information was derived from datasets on fires, and threatened ecosystems from CapeNature's spatial biodiversity datasets (Table 3).

Table 3: The criteria or sub-criteria and the datasets used to derive the necessary values

Criterion or sub-criterion	Datasets used to generate the priorities with a brief description of the calculations
Mean annual runoff (mm)	Mean annual runoff dataset as used for the surface water Strategic Water Source Areas (Le Maitre et al., 2018; Nel et al., 2017) bilinearly interpolated to a grid of 250x250 m to align with the grid used for the National Invasive Alien Plant Survey (Kotzé et al., 2010). Calculated per compartment using the *ArcGIS* version 10, Spatial Analyst zonal statistics tool. Areas with the greatest MAR get the highest priority (Figure 17).
Riparian and wetland areas	The Karatara catchment had extensive indigenous scrub and forest vegetation along the rivers, which is difficult to separate from the wetlands using remote sensing. The best estimate of the original extent of the river and wetland areas in catchment is the areas mapped as "Sources" and "Drains" for the Garden Route Initiative vegetation map (Vlok et al., 2008). We extracted these areas, overlaid them on the management compartments and calculated what proportion of each compartment was riparian/wetland or upland (Figure 18). The proportion of each compartment that was riparian or upland was multiplied by the MAR to generate the weights used in the prioritisation. Water flow regulation by wetlands is mainly a function of the occurrence and extent of valley bottom and river floodplain wetlands within a catchment. The wetlands of these types within the catchment were extracted from the NWM5, the wetlands dataset created for the 2018 National Biodiversity Assessment (Skowno et al., 2019). These wetlands are largely confined to the lower river valleys and the coastal plain (Figure 19). The wetlands were overlaid on the compartments to work out the proportion of each compartment with these types of wetlands.
Maintain fire regime	Current vegetation age derived from: (a) CapeNature's All Fires coverage for 2018 -19 for veld age (available from the Biodiversity GIS (https://www.sanbi.org/link/bgis-biodiversity-gis/) for their Protected and Mountain Catchment Areas; and (b) MODIS burnt area dataset converted to the days since the last fire for areas not included in the CapeNature dataset (data extracted from

	the Advanced Fire Information System database housed at the CSIR). There are no recorded fires across a large proportion of the area, which was assigned an age of 30 years although it could be 50 or more years, at least in parts. The area-weighted mean post-fire age was calculated for each compartment (Figure 21). Top priority is given to clearing areas approaching an ecologically acceptable age for burning or older than that.
Biodiversity conservation priorities, National Parks Expansion and Freshwater lakes	Cape Nature's Biodiversity Spatial Plan Handbook (Pool-Stanvliet et al., 2017) datasets on vegetation type threat status, Critical Biodiversity Areas (CBAs) type 1 and 2, and Ecological Support Areas 1 and 2 (downloaded from the B-GIS https://www.sanbi.org/link/bgis-biodiversity-gis/). Highest priority goes to CBAs, which include all remnants of threatened vegetation types, and Protected Areas (Figure 20). The Garden Route National Parks Expansion Areas dataset was provided by Johan Baard (personal communication, March 2020). Freshwater lakes data obtained from various sources: Swartvlei and adjacent water bodies from the SANParks compartments, Groenvlei from a map of waterbodies that was part of the national biodiversity assessment (Figure 18).

The spatial distribution of the mean annual runoff per compartment shows that the eastern part of K40D, including the coastal dunes near Groenvlei, gets higher rainfall and thus higher runoff than the western part (Figure 17). The slopes of the Outeniqua Mountains in the northern part of K40C also have higher rainfall, and thus runoff, than the plateau area in the southern part of K40C.

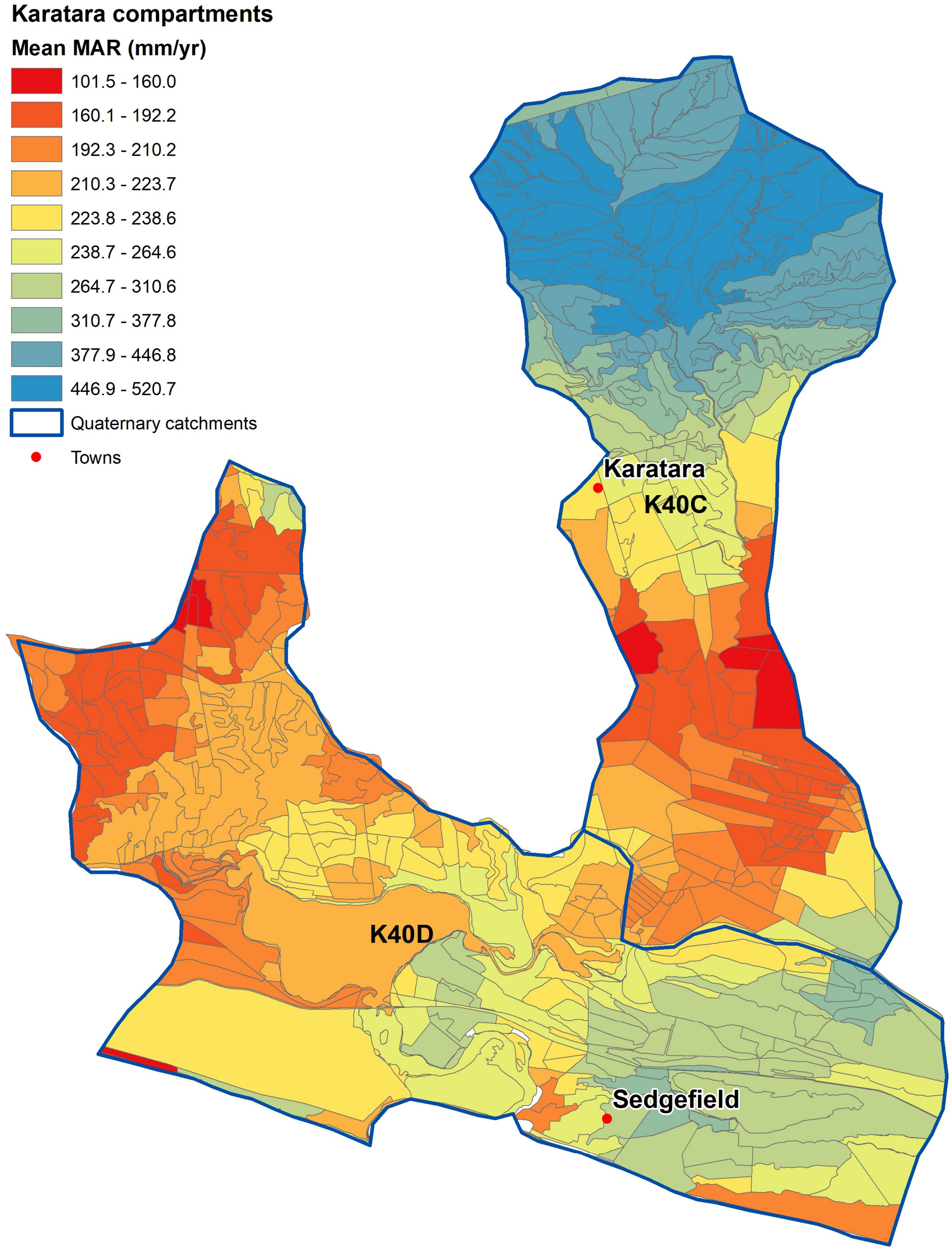

Figure 17: Mean annual runoff per compartment in the Karatara catchments. See Table 3 for more information.

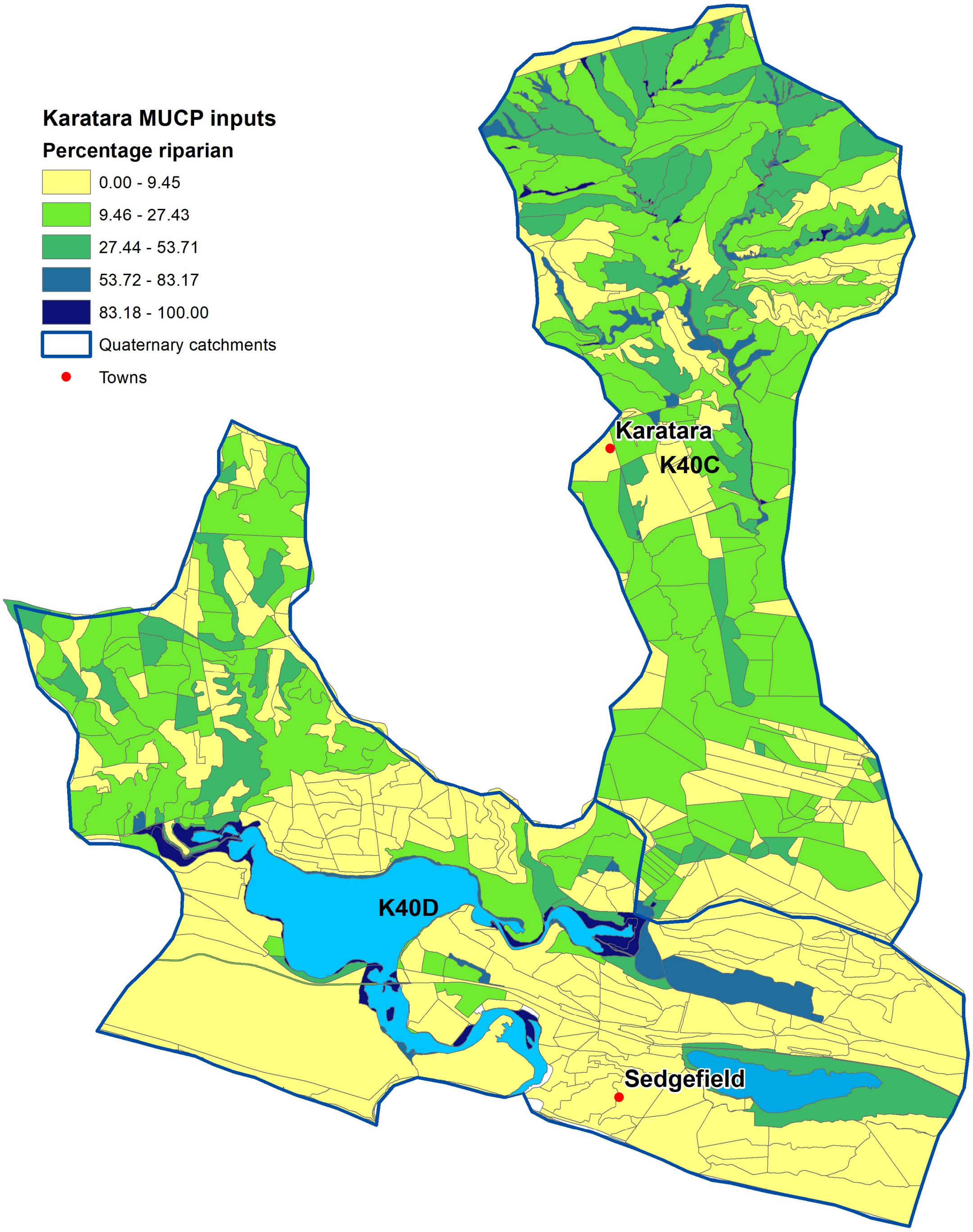

Figure 18: The percentage of each compartment that is riparian based on the Garden Route Initiative vegetation map. Freshwater lakes are highlighted in medium blue. For more information, see Table 3.

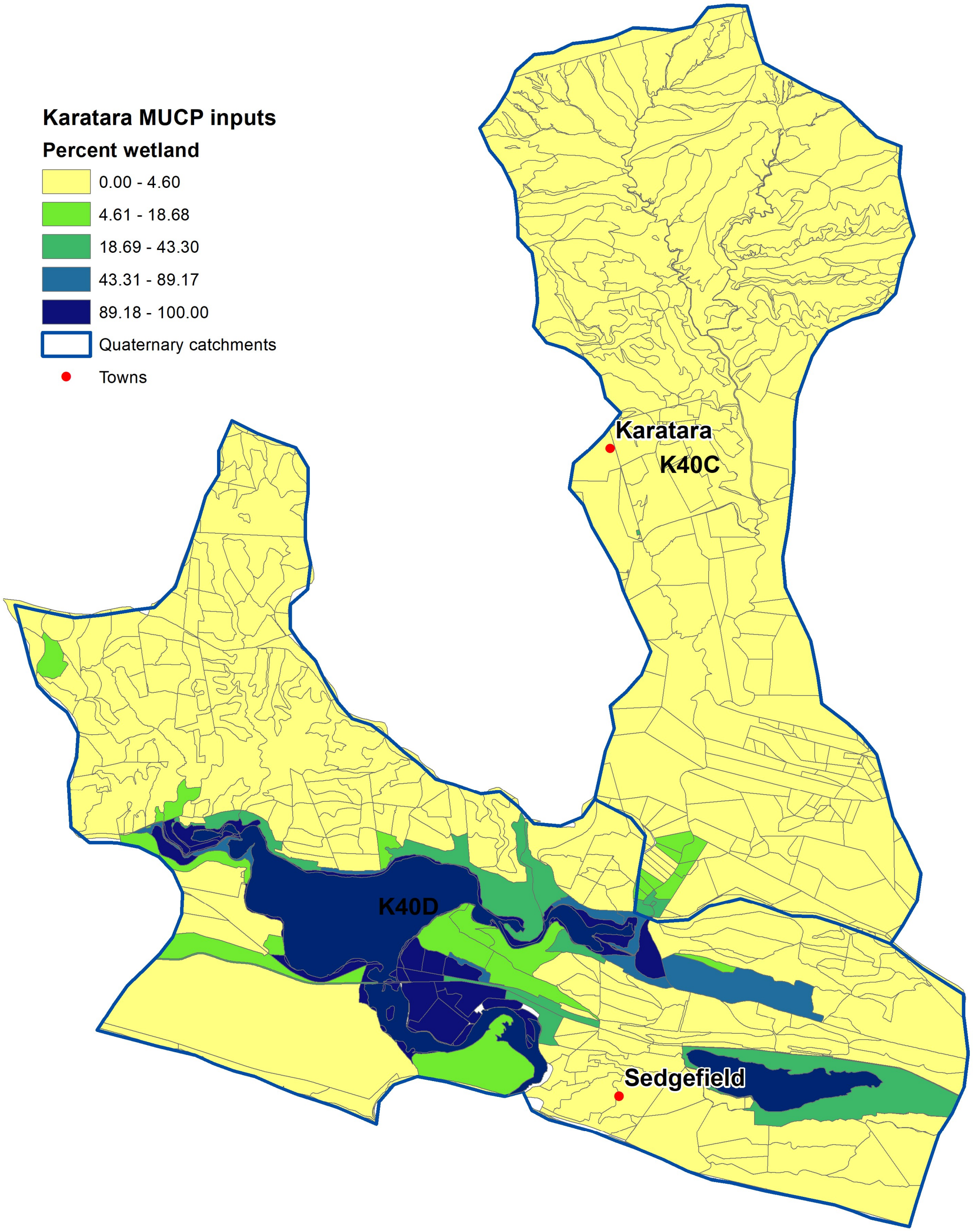

Figure 19: The percentage of each compartment that is wetlands based on the national inland aquatic ecosystems database. For more information, see Table 3. This database underestimates wetlands in indigenous forest areas.

The criterion for including wetlands in the prioritisation was their flow regulation function. The rivers are typically deeply incised with narrow floodplains and little flow regulation, while the streams are generally quite narrow. The only wetland than can play a flow regulation function are those on the coastal floodplain, particularly those adjacent to the freshwater lakes. The reed beds and saline marshes around the lakes can absorb flood waters as the lake water levels rise and so, arguably, have a flood regulation function.

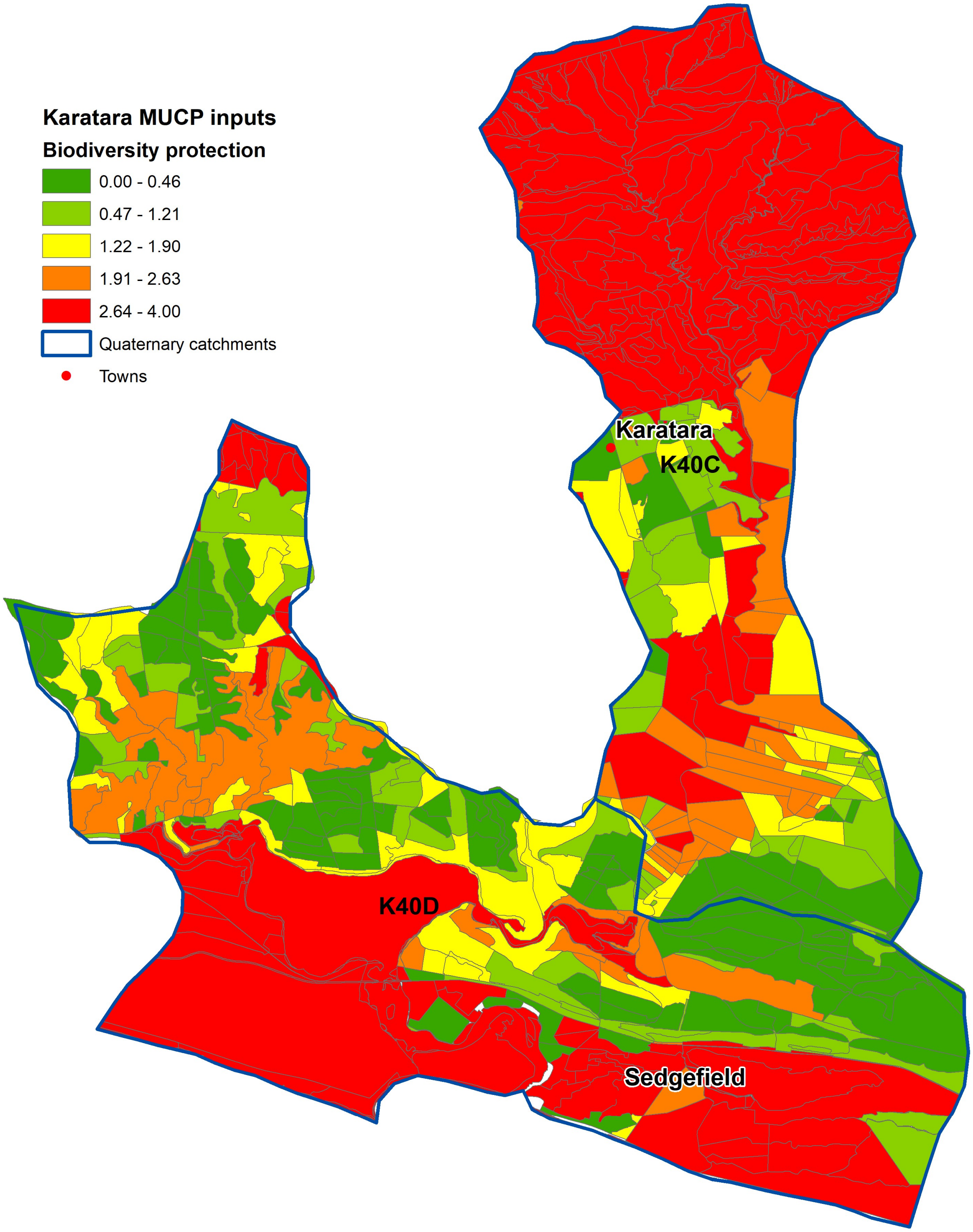

Figure 20: The importance of biodiversity protection in each compartment in the Karatara catchments. The greater the value the higher the priority. Protect Areas are also considered high priority. For more information, see Table 3.

This map shows the occurrence of conservation priorities (e.g. critical biodiversity areas) and of protected areas in each compartment (Figure 20). They clearly highlight the protected areas, including contracted private land in the coastal plain and dune systems, and the Garden Route National Park in the northern parts of both catchments. The key role of natural and near-natural areas, which potentially form conservation corridors between the mountains and the coast, is also highlighted.

5.4 Datasets used in the creation of the compartments, mapped invaded units and NBALs

The MUCP tool requires datasets for the management units (compartments), all known or mapped invasions and treated areas (i.e. NBALs) (Table 4)

Table 4 The basic spatial datasets required by the MUCP tool, data sources and processing.

Spatial dataset & attributes	Source datasets and data processing
Compartments	SANParks management compartments dated March 2020 as supplied by Johan Baard (personal communication), CapeNature's mini-compartments (supplied by CapeNature), a compartment dataset developed for Natural Resource Management programmes (Department of Forestry, Fisheries and Environment) for use for planning, including the MUCP tool, and cadastral data from the Surveyor General (National Geo-spatial Information system) as supplied by Andrew Wannenburgh. The compartments take account of natural features as well as administrative boundaries (cadastres). Riparian compartments were selected using those that included or adjoined rivers extracted from the database used for the National Biodiversity Assessment (Skowno et al., 2019).
Mapped Invaded Units	All the mapped invasion data that could be used including the attribute data in CapeNature's mini-compartment dataset for their protected areas. We also obtained an update of the mapping of invasions done for the Garden Route Initiative in 2008 (Vromans et al., 2010) prepared by Paul Buchholz. This information was combined with the NBAL data (see below) to give as complete a coverage as possible.
Treated invaded units (NBALs)	Data for treated areas supplied by Andrew Wannenburgh (NRM programmes) from the WIMS database; the records for the most recent treatment contract were taken as representing the current state. NBALs that had not been followed-up for 5 years or more were considered untreated and merged with the MIU information.

5.5 Priorities estimated using the AHP model

The values for each compartment for each of the variables, which represent each of the criteria and sub-criteria in the model, were extracted and compiled in a spreadsheet. The export Grid option in the software was used to create a spreadsheet template into which the values for each compartment (alternative) could be copied. The values from this prioritisation dataset were copied to the correct columns in the template spreadsheet. The completed template was then imported into the AHP grid and loaded into the software for processing. The resulting priorities are shown below.

The priorities areas for achieving the goal appear counter-intuitive because rainfall generally increase with altitude, so the MAR also tended to follow this pattern. In this catchment, the rainfall is relatively high on the coastal dunes and on the slopes of the coastal plateau. The top of the plateau, which includes most of the lower part of quaternary K40C, has lower rainfall but the rainfall then increase again in the upper catchment. The inclusion of river systems and wetlands, combined with the extensive flood-regulating wetlands associated with the lakes, is the reason why compartments that include these systems get the highest priority. This includes the lake areas, which are included under the restoration criteria as a priority.

Again, it is important to distinguish between the priorities given to compartments and the resources, which are required to achieve effective control in those compartments. These wetlands may only have limited invasions and so may only require small allocations of resources to achieve effective control. The remaining resources can then be allocated to lower priority compartments.

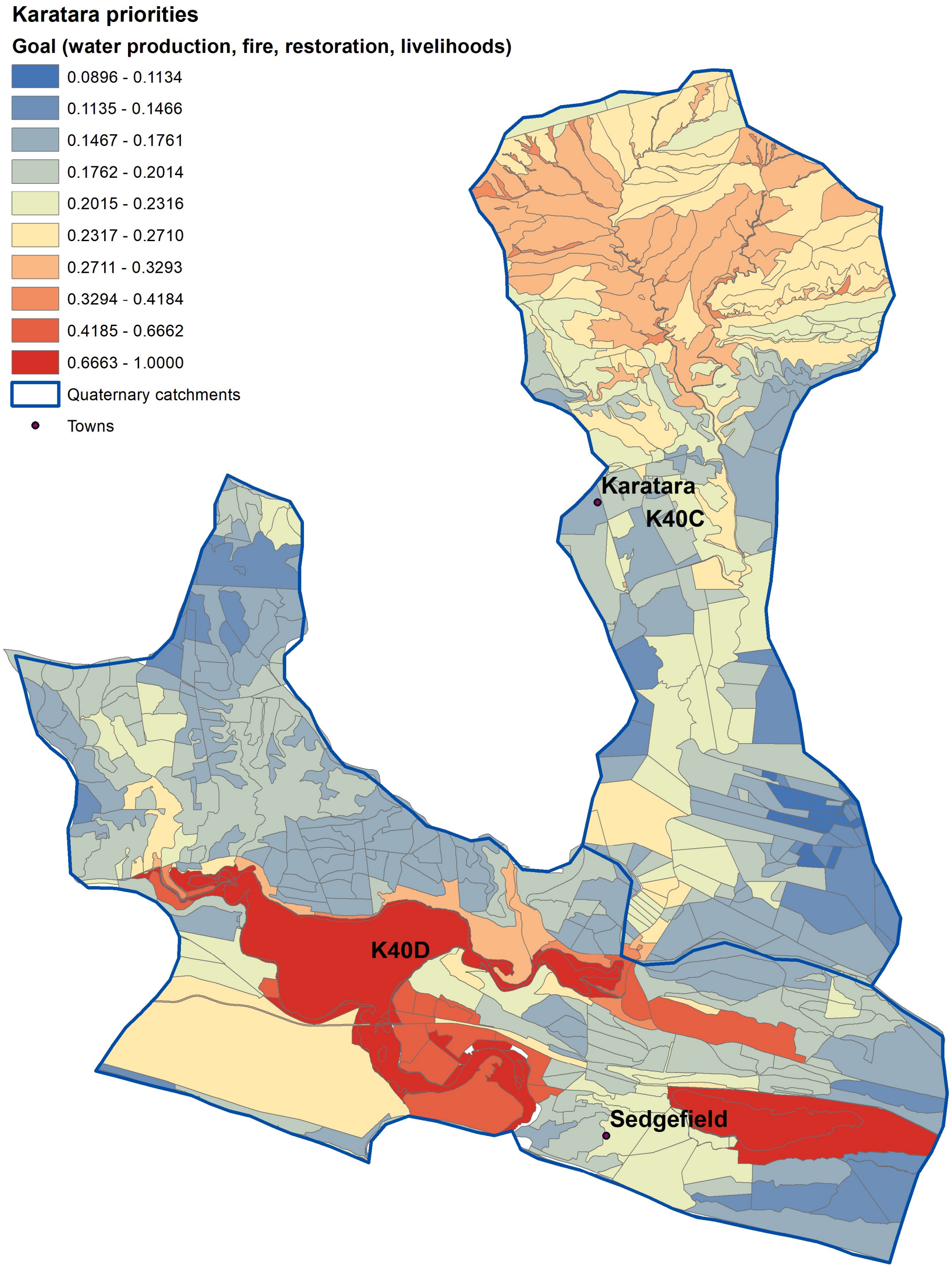

Figure 21: The Karatara catchments showing the priority values for each management compartment based on the overall goal as defined in AHP model (Figure 16), and the values for each compartment of each of the variables in the model.

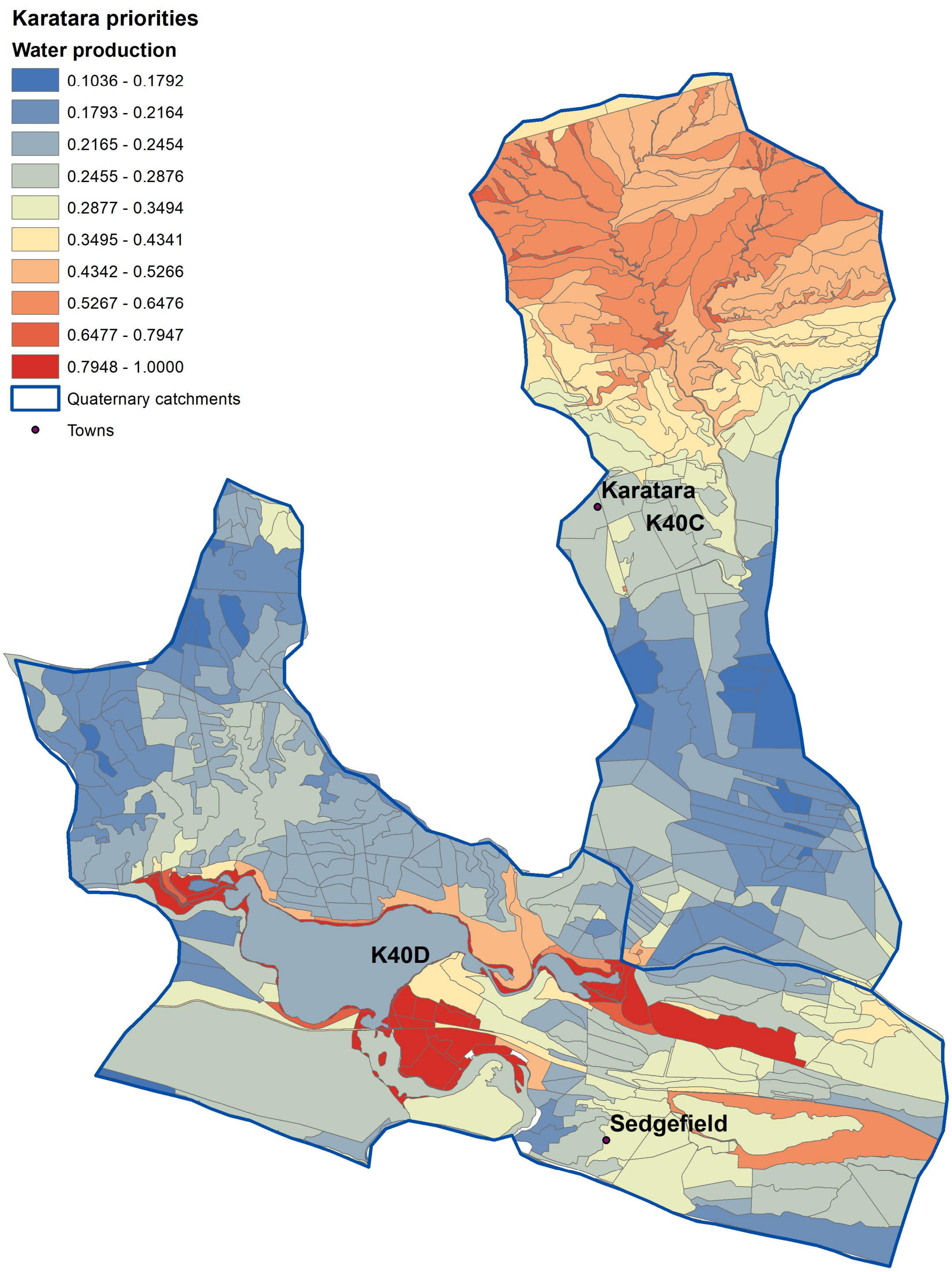

Figure 22: The Karatara catchments showing the priority values for each management compartment based on the water production criteria as defined in AHP model (Figure 16), and the values for each compartment of each of the variables in the model.

The priorities for water production are closely aligned with those for the goal, with the exception of the lakes themselves. The fringing wetlands and areas around the Sedgefield Island settlement are given a high priority, which is appropriate given the invasions of

Leptospermum laevigatum in this area, quite a lot of which has already been treated.

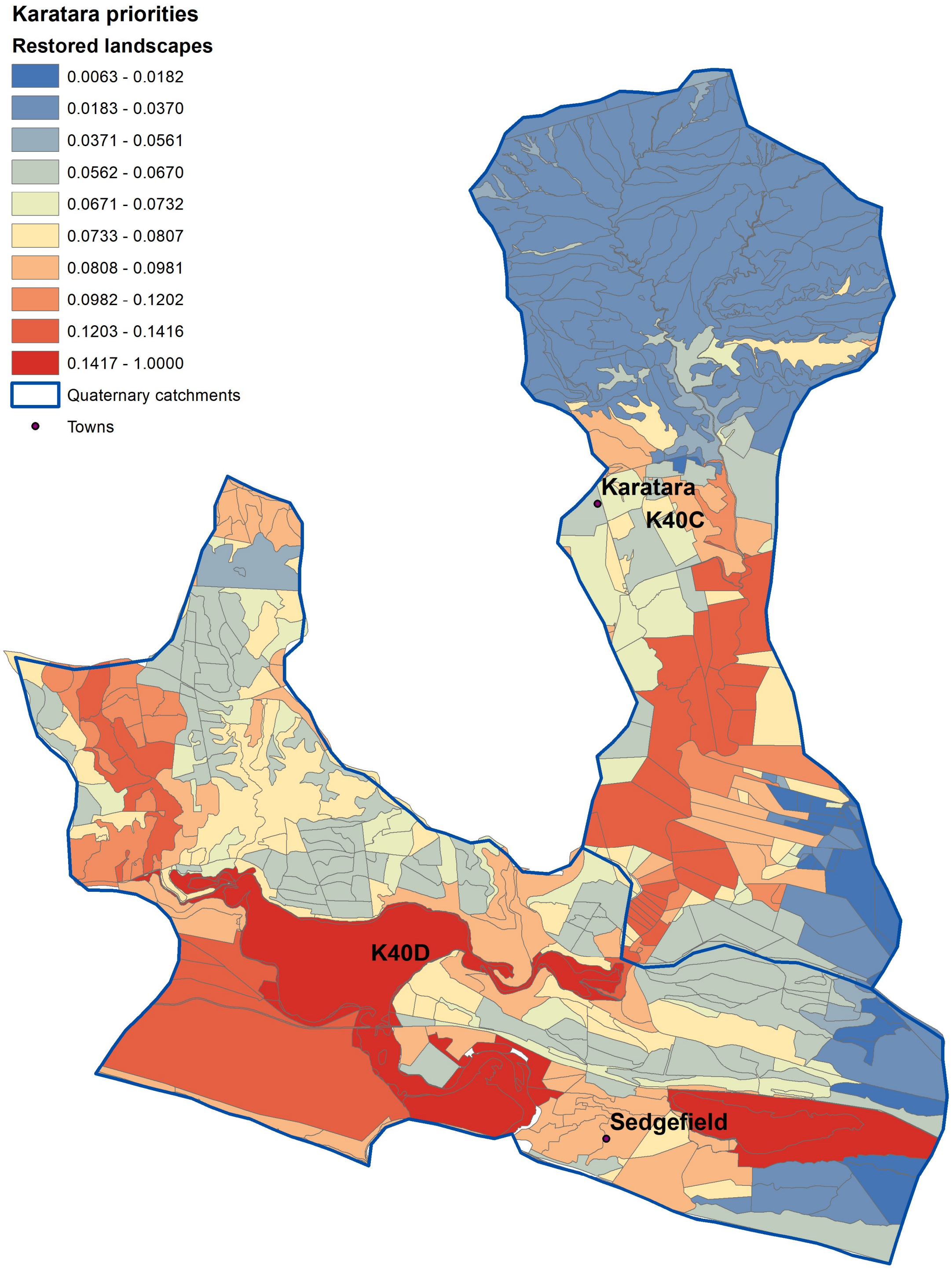

Figure 23: The Karatara catchments showing the priority values for each management compartment based on the restoration criteria as defined in AHP model (Figure 16), and the values for each compartment of each of the variables in the model.

The restoration priorities once again highlight the wetlands and the lakes as well as the potential conservation corridors between the coastal plains and sand dune systems and the upper parts of the catchments. Fire risks are currently high to very high in this catchment, except in the areas burnt in the Knysna fires on the eastern side in 2017, and the George-Karatara fires in 2018, which burnt the upper part of catchment K40C.

5.6 Outputs of the MUCP tool: priorities and resource requirements

The MUCP system generates a number of outputs, most of which are best viewed using the facilities in the system (e.g. the maps generated by the Visualisation section) or by exporting the datasets to spreadsheets (e.g. the treatment schedules and budgets).

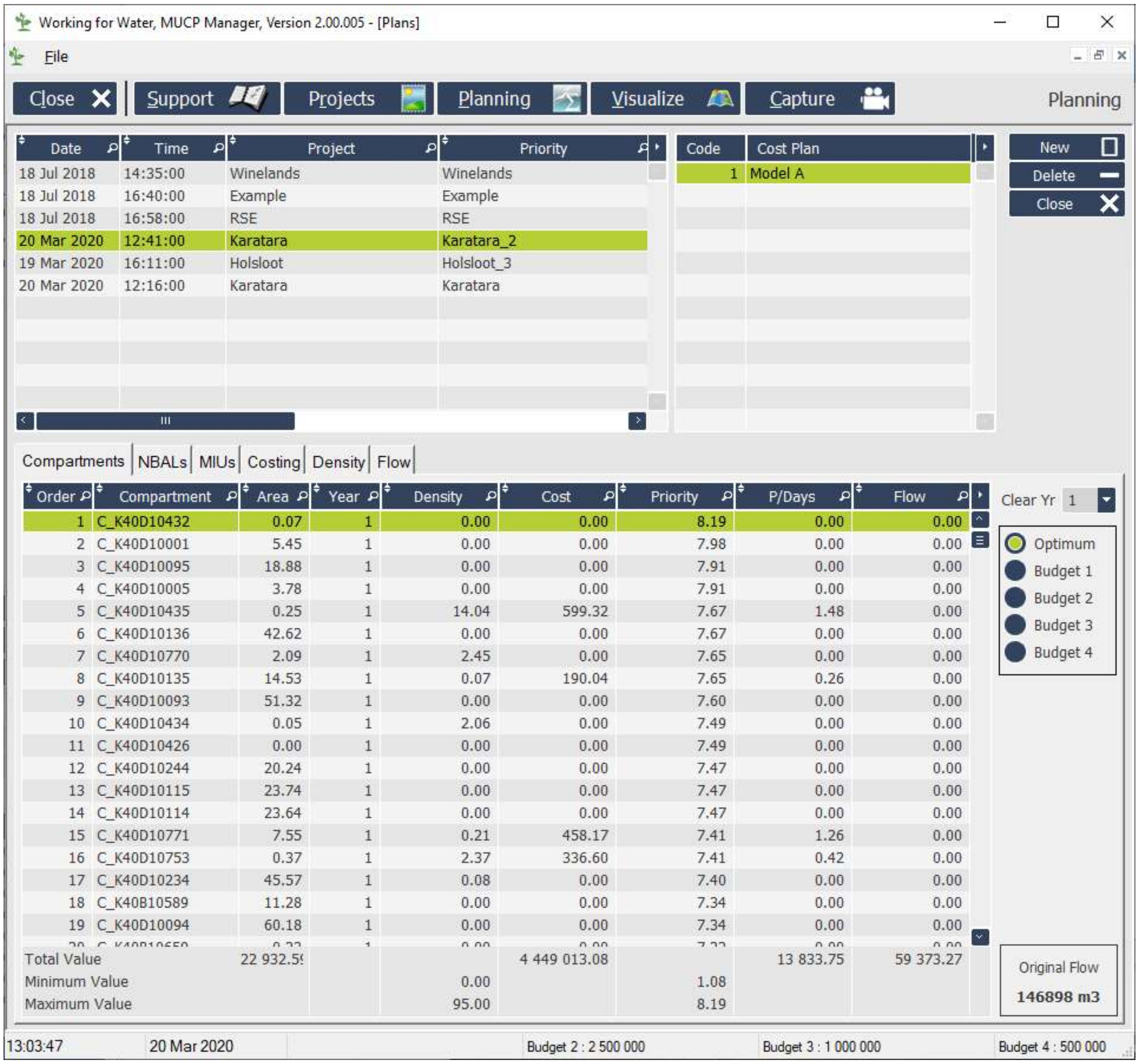

Figure 24: A part of the planned treatment schedule showing cost information for each compartment for each of the next 20 years for the Optimum budget. The optimal budget is generated by the system to be sufficient to treat the entire catchment in as short a time as possible. For more information, see the text.

This screen capture from the MUCP system (Figure 31) shows the information displayed for a particular cost scenario (Optimum budget) for Karatara. This model used the global priority weights as generated in the workshop (Figure 16) converted into a priority model (Karatara_2, Figure 24 upper pane). Selecting compartment tab displays the unique Compartment code, its area, the treatment year, the density of the invasions, the planned budget, priority, person days and the increase in runoff that could be expected in m³/year in the lower pane. The data also show that six of the top 10 top priority compartments have no invasions, making the distinction between the priority scores, and the resource allocations required for the treatment, clear. The summaries at the bottom of the lower pane show that the optimal budget in year one would be about R4.5 million using the Model A cost model, shown in the upper right of the top pane, and the resource allocations to different compartments.

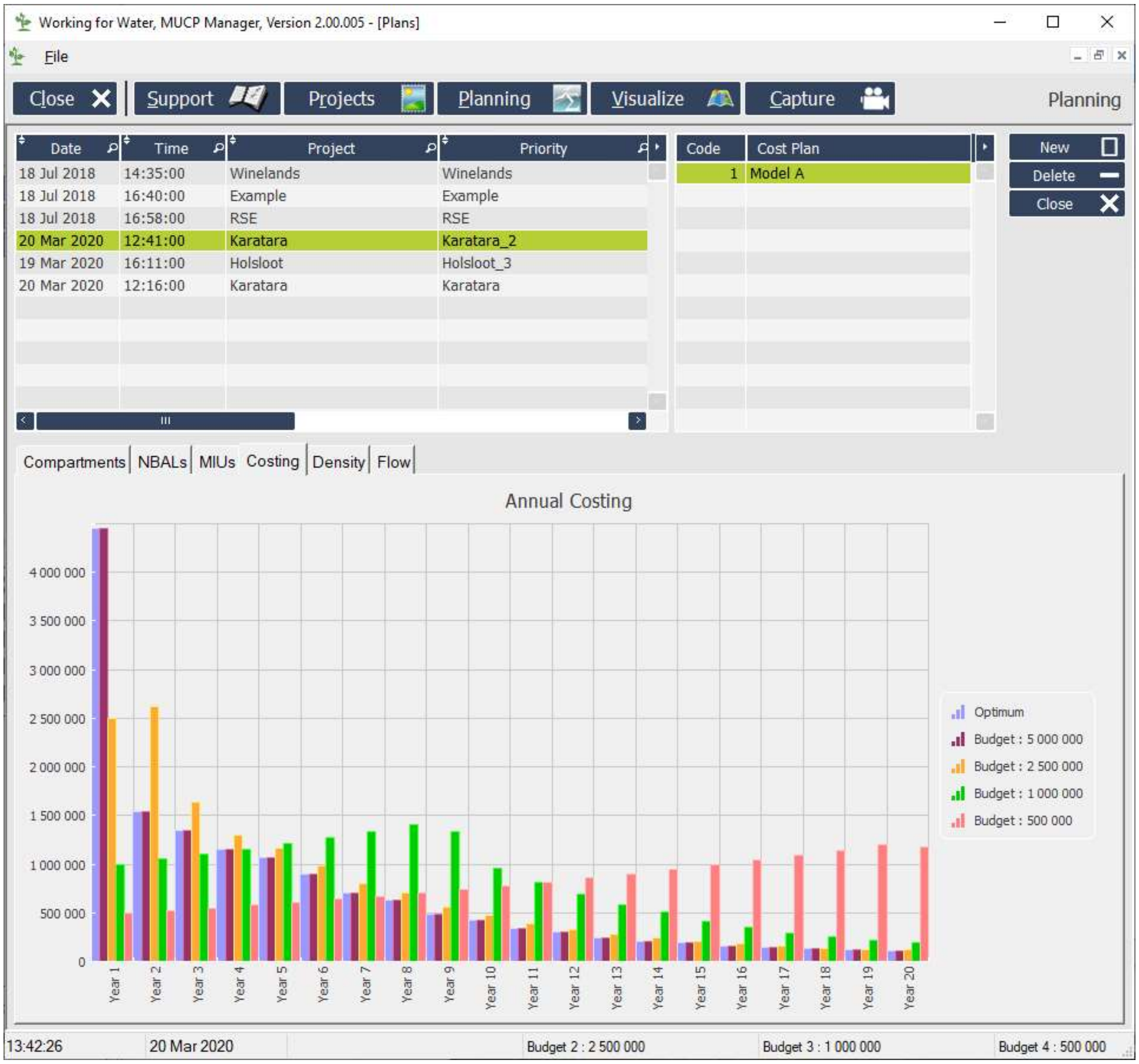

Figure 25: The information displayed when the Costing tab is selected showing the planned annual budgets for different budget ceilings over the 20 year planning horizon used by the MUCP system. The budgets all escalate at 6% per year to allow for inflation.

The Costing or planned expenditure tab displays a timeline of the annual expenditure that will be required to reduce the densities of all the invasions in the catchment to maintenance levels (Figure 25). The Optimal budget is automatically calculated by the system and is included to illustrate the funding required to reduce invasions in the minimum amount of time. The top three budgets that the user sets are all sufficient to get the invasions down to low levels within 20 years. The lowest budget of R0.5 million continues to increase based on the inflation escalation until year 19 and then only declines slightly.

The timeline of the decrease in the mean density of the invasions in the catchment (Figure 26) shows that the largest annual budget of R5.0 million will reduce the densities within 20 years. The budget of R2.5 million initially lags but then catches up within 10 years. The next lowest budget, R1.0 million, shows a greater lag but makes up the difference by year 20, whilst the lowest budget of R0.5 million shows an initial increase in density up to year 6 before starting to decline. It does not achieve maintenance levels within 20 years.

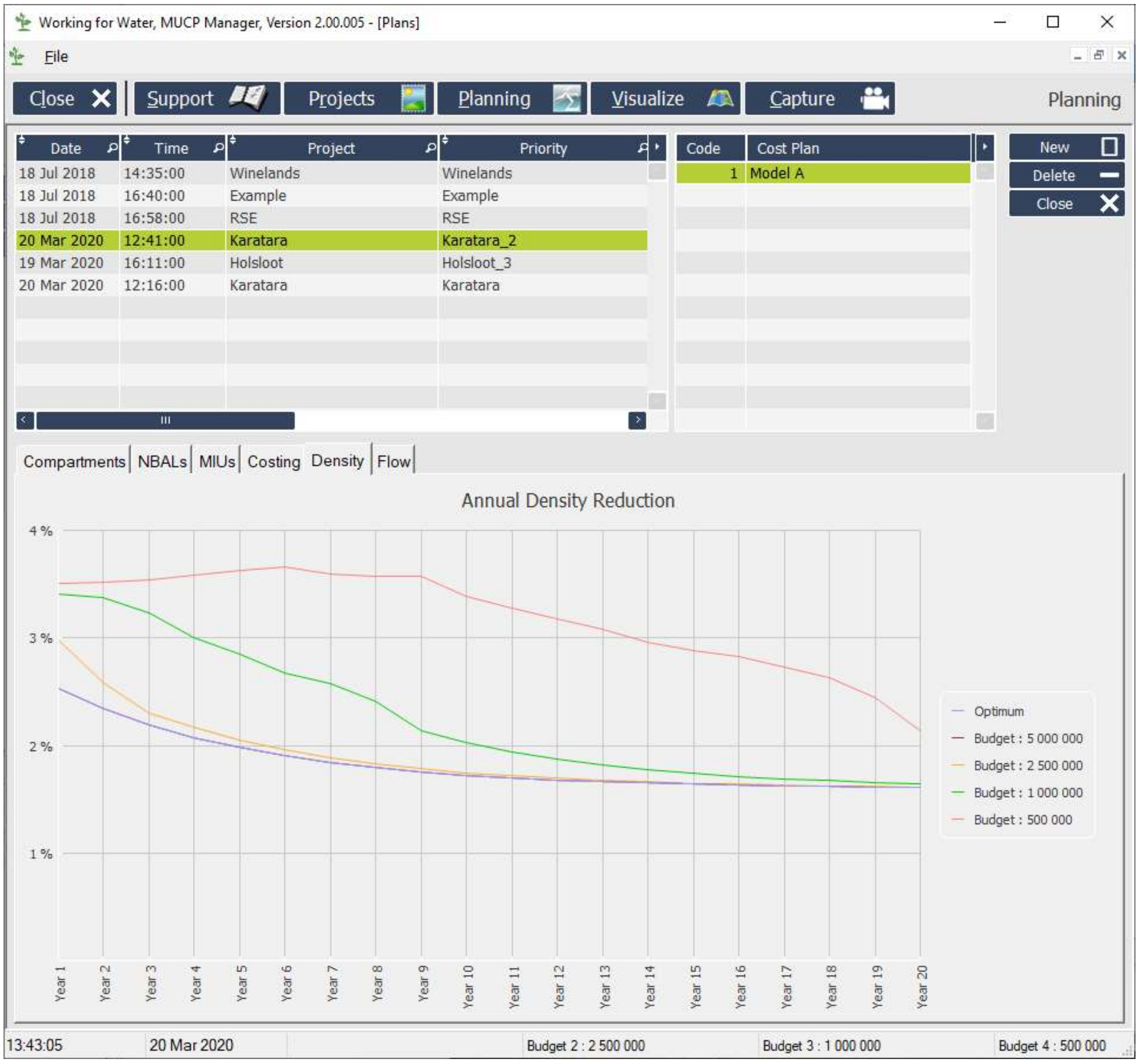

Figure 26: The planned rate of reduction in the density of the invasions over 20-year planning horizon used by the MUCP system.

The decline in the volume of water used by the invasions (Figure 27) is relatively high in the first year, but decreases in the later years. The R5.0 million budget results in the most rapid decrease (as expected) and the R2.5 million is not far behind. The lowest two budgets do quite well in year 1 but both soon plateau, with the smallest budget initially losing ground and only having a positive effect from year 15 onwards.

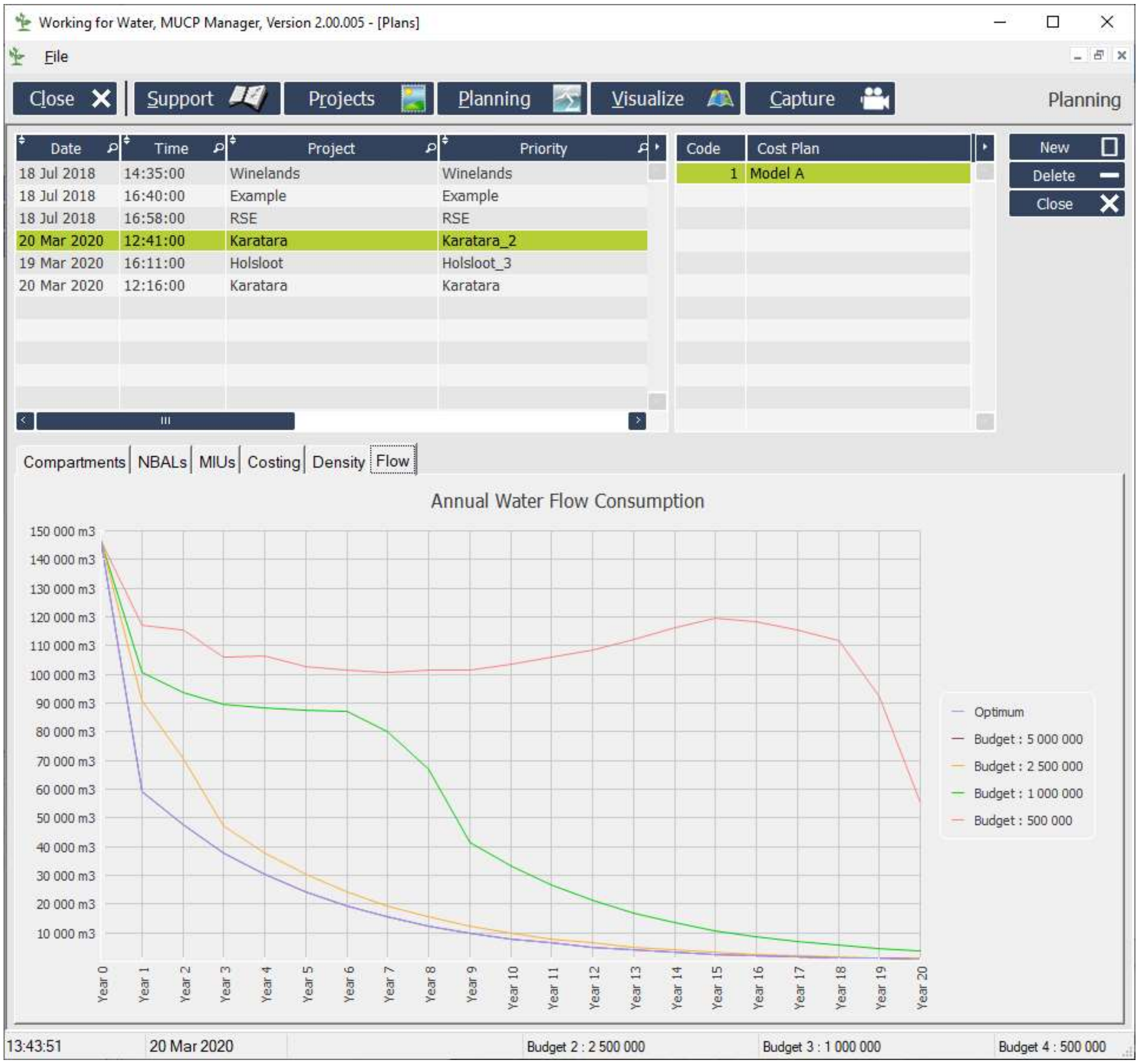

Figure 27: The projected decline in the annual water flow consumption (i.e. the additional amount of water used each year by the invading plant species) for each planned budget.

The multi-criteria AHP model and the MUCP system do not calculate their priorities in the same way from the weight so the priorities given to the different compartments are not the same. They do show broadly similar spatial patterns although there are some clear differences between (Figure 21 versus Figure 28). The highest priorities are given to a set of compartments bordering on Swartvlei and Sedgefield, and one compartment located in the Garden Route National Park. The next set of priorities is widely scattered across the catchments, and seems to be due to the weights given to biodiversity protection, including wetlands and protected areas. These provisional results will still be evaluated with the workshop participants and refined where necessary.

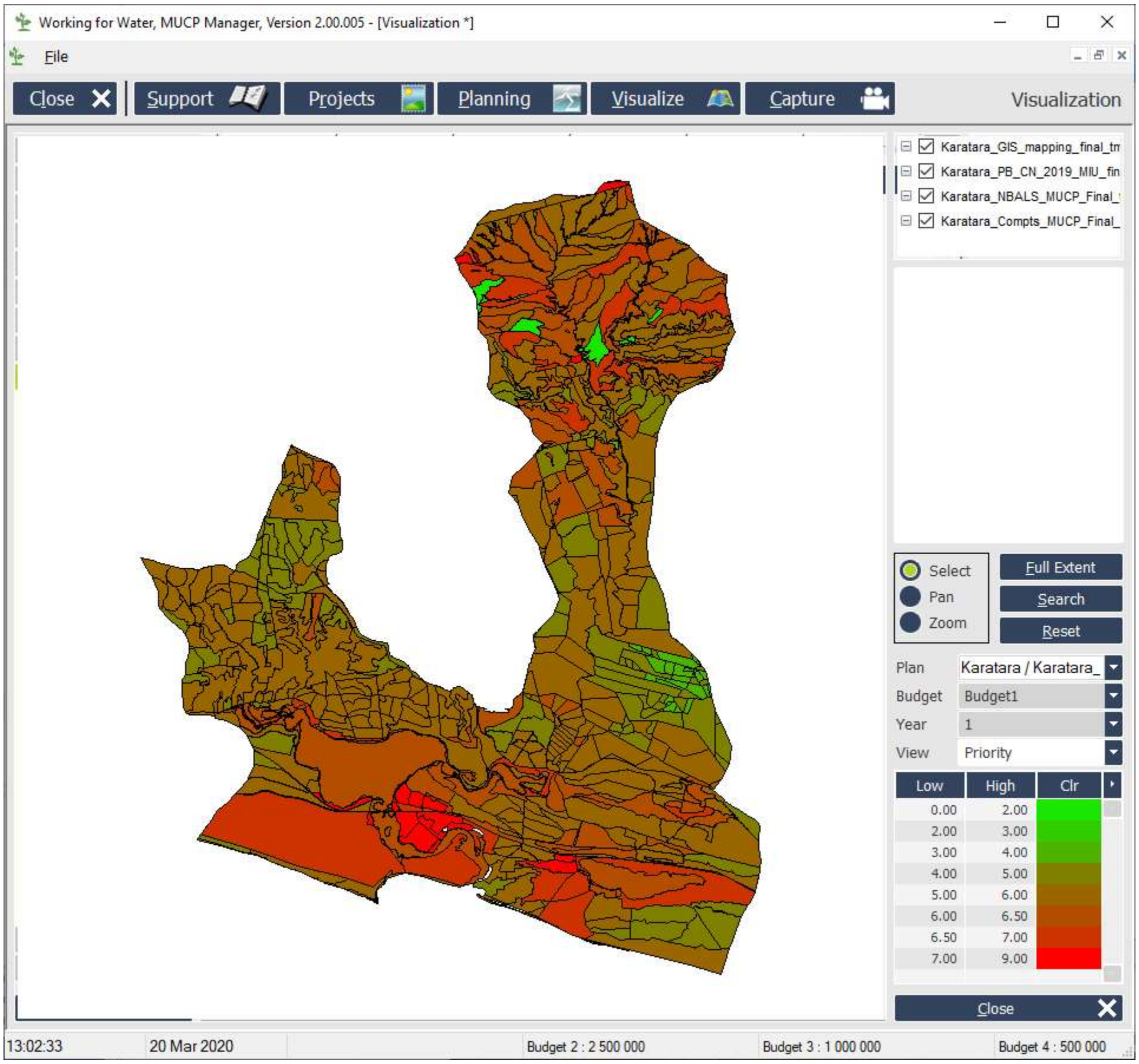

Figure 28: The priority calculated for each compartment by the MUCP system based on the global weights given to the different criteria in the multi-criteria model developed in the workshop (see Figure 16).

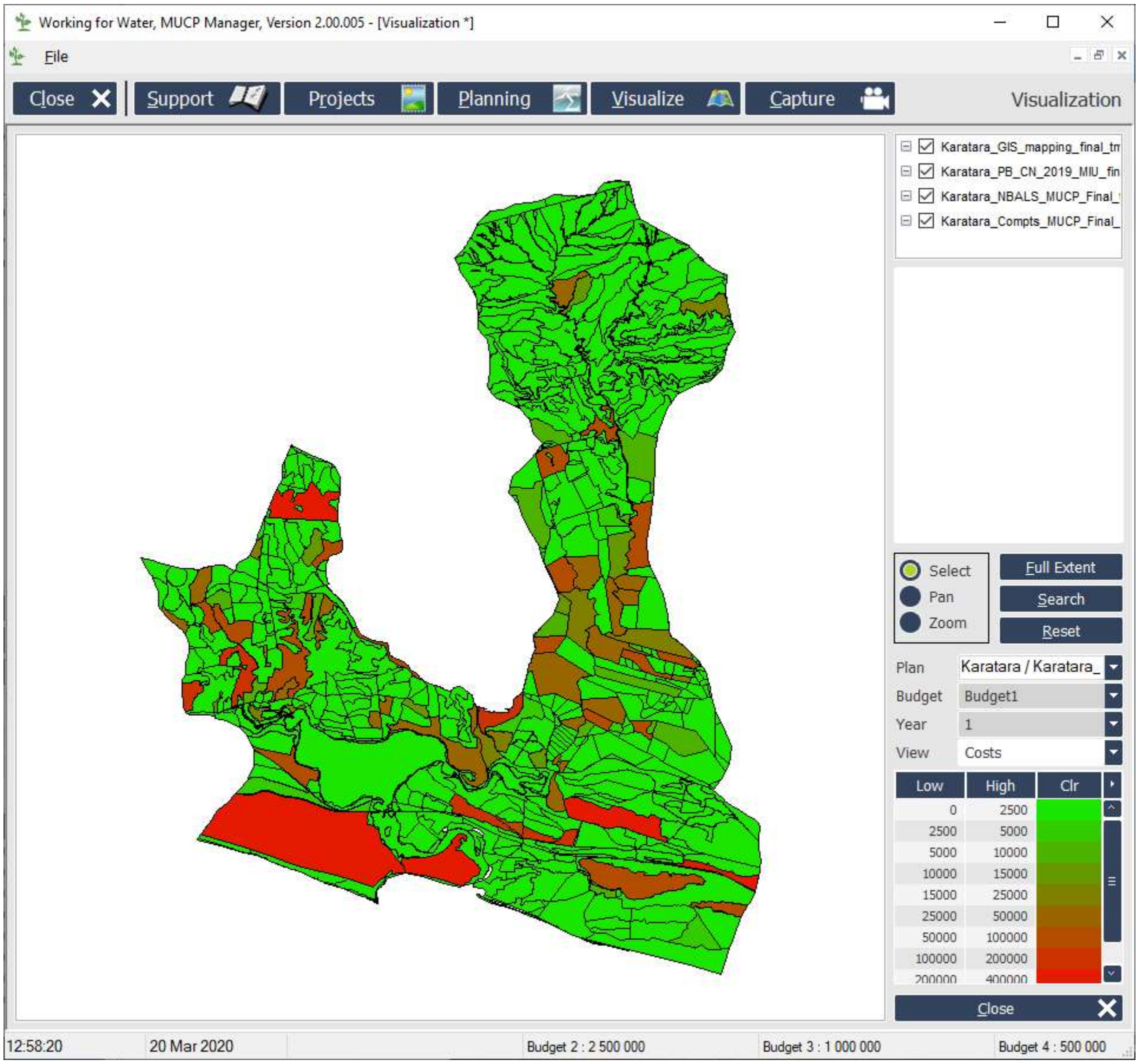

Figure 29: The budget allocations for the different compartments in the Karatara catchment for year 1 and Budget 1 of a maximum of R5 million (Figure 27).

A comparison of the planned budget allocations to compartments for the largest annual budget of R5 million (Figure 29) and the lowest annual budget of R0.5 million (Figure 30) shows a drastic decrease in number of compartments being treated in year one.

This section illustrates one outcome of the clearing programme modelling exercise based the set of priorities, the potential budgets, the costing models used for the treatments and the treatment norms. The MUCP system also allows users to adjust factors which change the resources required for successive treatments. An example is that the annual rate of increase in density can be set for each species. This has a substantial impact, because invasions in untreated compartments are continually increasing in density, so that the treatments costs are escalate. Likewise, the reductions in density, following either initial clearing or follow-ups on a given species, can be altered to indicate greater effectiveness, or to reduce effectiveness. If the efficacy is low (i.e. densities only decline slowly with successive treatments) then the users will have to allocate more resources per year to follow-up treatments of a given invasion, increasing the annual budget or reducing the treated area. If the efficacy is high, then densities and resource requirements will decrease more rapidly and a greater area can be treated. The default values were used in these plans, but the final values can be set by the participants in the planning exercise.

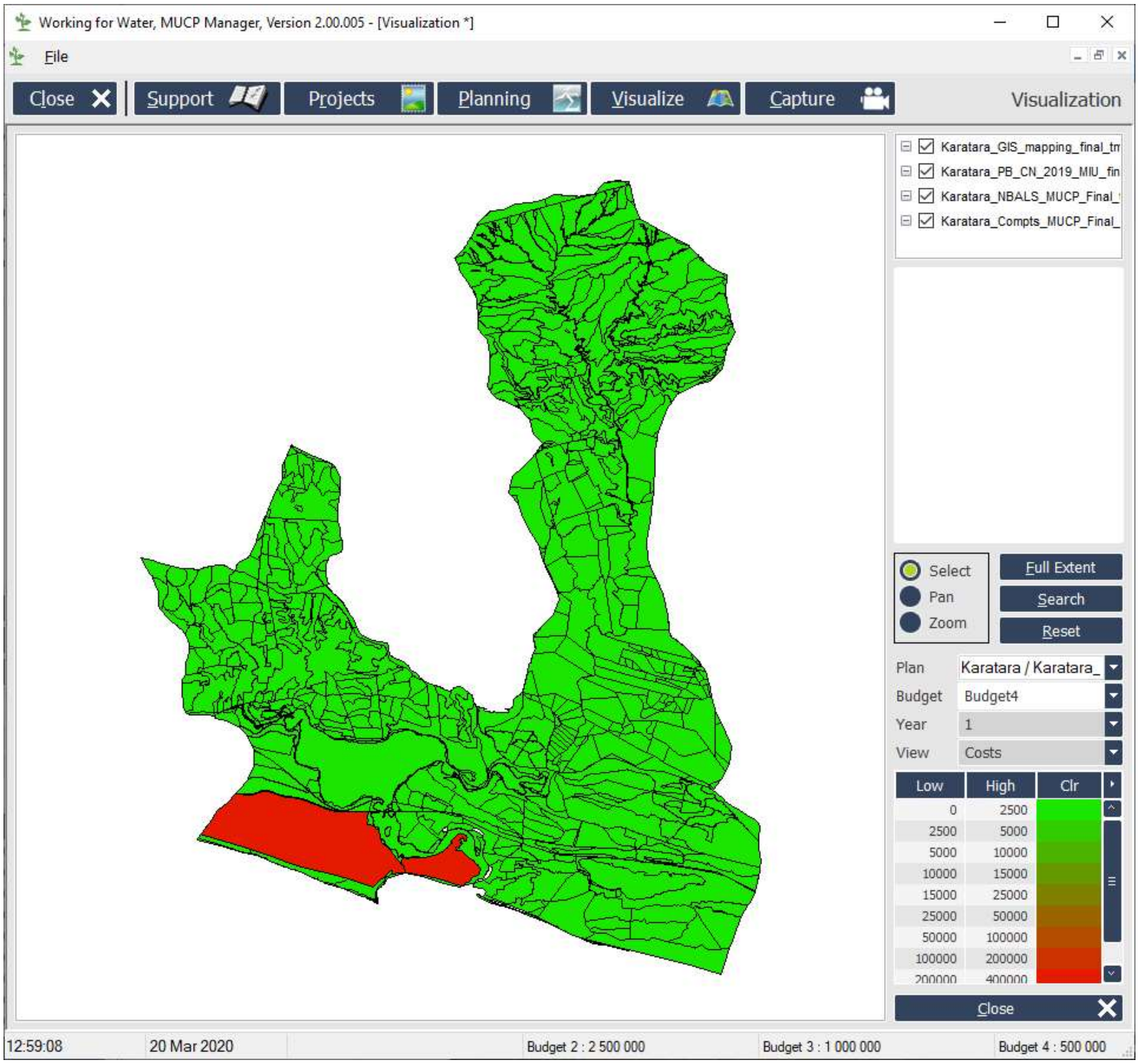

Figure 30: The budgets allocations for the different compartments in the Karatara catchment for year 1 and Budget 4 of a maximum of R500 thousand per year.

6 KEURBOOMS

6.1 CATCHMENT DESCRIPTION

The Keurbooms catchment is by far the largest of those chosen for an MUCP and includes nine quinary catchments with a total area of 85 896 ha. The quinary catchment boundaries are reasonably well-aligned with those to the five quaternary catchments (K60A-K60E) giving them a similar total area (Table 5) (Bailey and Pitman, 2015). The catchment with the highest water production is K60D, which also produces 42.1% of all the runoff of all five quaternary catchments. K60D includes the catchments of the Palmiet and Dwars Rivers, which drain the northern slopes of the Outeniqua Mountains and the southern slopes of the Langkloof Mountains, which accounts for the relatively high runoff. Catchments K60A and K60B include areas of relatively low rainfall, which reduces their runoff. They are characterised by arid fynbos in the valleys and middle slopes.

The main water supply for the town of Plettenberg Bay, and the adjacent urban areas in the Bitou Municipality, is the Keurbooms River, which is supplemented Roodefontein Dam in the Piesang River catchment and from boreholes, and also a small desalination plant (which is apparently only used during the summer months). The water situation for the town of Plettenberg Bay was classified as being affected by drought at 0-5 year intervals in 2011 and has deteriorated since then due to further urban expansion and population growth (DEA&DP, 2018b; DWS, 2014).

Table 5: Areas and estimated mean annual runoff for the quaternary catchments comprising the Keurbooms River catchment (Bailey and Pitman, 2015).

Quaternary	Area (ha)	MAR (mm)	MAR (mill. m^3)
K60A	16 132	86.3	13.9
K60B	14 269	121.7	17.4
K60C	16 092	124.8	20.1
K60D	29 252	152.4	44.6
K60E	9 999	101.0	10.1
Total	85 743	123.7	106.0

The catchment falls primarily into the Fynbos Biome but includes portions of the forest biome on the southern slopes of the Langkloof Mountains and valleys in the coastal platform, and arid fynbos in the inland valleys. The dominant fynbos vegetation types comprise North and South Outeniqua Sandstone Fynbos, Tsitsikamma Sandstone Fynbos, Kouga Sandstone Fynbos and remnants of Garden Route Shale Fynbos in the lower catchment. There are remnants of Cape Estuarine Salt Marshes associated with the estuary. The indigenous forest vegetation type is Southern Afrotemperate Forest. There are extensive invasions in all the catchments, with essentially all of the naturally vegetated areas being invaded (Table 6). There are limited areas of cultivated land in the valley bottoms in the western part of the upper catchment and the southern part of the catchment.

Alien plant invasions are estimated to have reduced mean annual runoff in the Keurbooms River by nearly 20% by 2007 (Le Maitre et al., 2013). The greatest reductions in mean annual runoff were estimated for catchments K60B-K60D. Even at a conservative rate of invasion of 5% per annum, the reductions will increase to about 23% by 2032 and will exceed 30% in quaternary K60C. The main invaders in the fynbos uplands are pines (predominantly *Pinus pinaster*), and *Hakea* species, with *Acacia mearnsii* and *A. melanoxylon* on the lower slopes, in the river floodplains and invading the forest and scrub vegetation.

*Table 6: Estimated extent of invasions, mainly pines, hakea and wattles (*Acacia spp.*) and their impacts on mean annual runoff based on data from the National Invasive Alien Plant Survey* (Kotzé et al., 2010; Le Maitre et al., 2013).

Quaternary	Total invaded (ha)	Total Condensed (ha)	Runoff reduction 2007 (%)	Runoff reduction 2032 (%)
K60A	11 731	2 190	9.77	12.13
K60B	11 025	3 849	22.60	28.10
K60C	10 438	5 031	25.63	31.30
K60D	26 100	7 135	21.10	23.92
K60E	3 044	183	1.25	2.60

Total	62 338	18 388	19.90	22.63

The mapped information on invasions is considered satisfactory for the CapeNature Reserves, but poor for the rest of the catchment which was last mapped in 2008 (Vromans et al., 2010). We have made extensive use of the update of the 2008 data provided by Paul Buchholz but this involved applying some simple rules, which do not include adjustments for events like fires during the intervening years. The result is that our confidence in the estimates of the resources requirements generated by the model is low. We are still doing additional checks on the model outputs because of input data issues.

6.2 WORKSHOP AND MODEL DEVELOPMENT

The workshops for the Karatara and Keurbooms catchments were held concurrently. More details are given in section 1. When it came to defining a goal for the Keurbooms catchment, the current state of the invasions was seen as such that a time-frame of 2030 (as used for the Karatara) is far too short to make tangible progress. So the year was changed to 2045 but the rest of the wording was left the same as that for the Karatara MUCP:

By 2045 a collaborative and coordinated management effort has increased water production, established an acceptable fire regime, restored river and wetland systems, biodiversity, while generating sustainable livelihoods and increasing resilience to climate change for all inhabitants

The next step was to identify criteria and sub-criteria to use for prioritising areas for management actions. The workshop participants based the Keurbooms prioritisation criteria on those used in the Karatara catchment with modifications to reflect the environmental characteristics of the Keurbooms catchment. Again, the top-level criteria were water production and restoring functional landscapes, but there was a shift in the weighting to reflect the greater importance of water production in this catchment. The water quality sub-criterion was also modified to focus on palmiet wetlands. This is because they are often relatively extensive and important both ecologically and for water flow and quality regulation, as well as being vulnerable to alien plant invasions (Rebelo et al., 2018). We have subsequently discovered that the catchment has relatively few river floodplains that are of the geomorphological types that support extensive wetlands, including palmiet wetlands[2]. The sub-criteria under functional landscapes were modified to prioritise areas identified for the expansion of the Garden Route National Park within the Keurbooms catchment. Overall, treating invaded areas to increase water production (water quantity) got the top priority (62.5% of the whole model) followed by the clearing of the upland areas in the catchment (41.7%).

[2] For more information see the discussion of the datasets used to determine the priorities

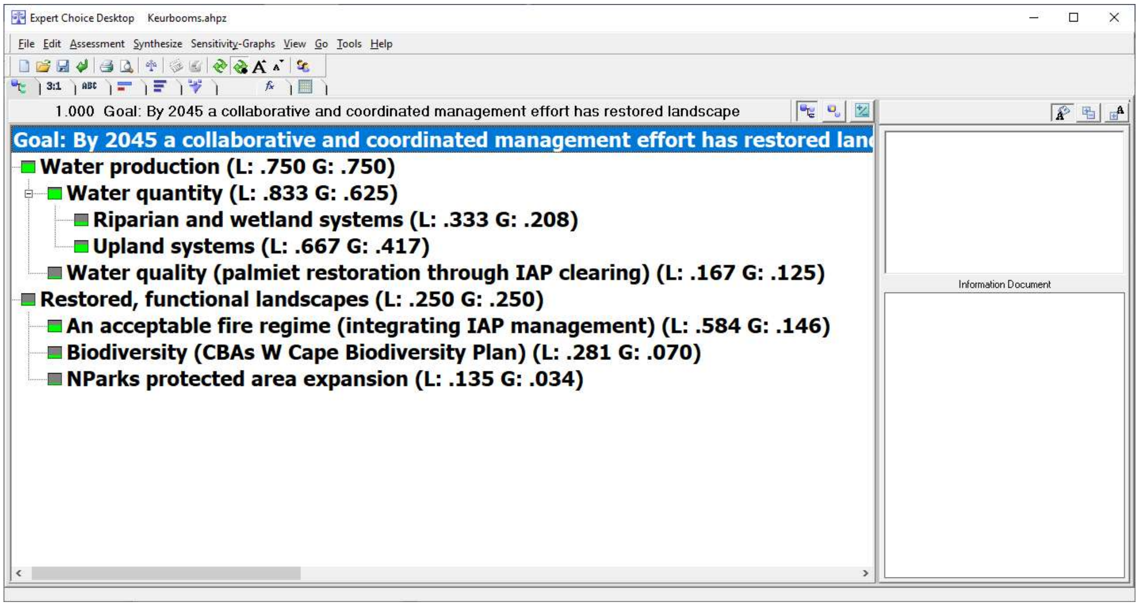

Figure 31: The AHP model developed for prioritising management units within the Keurbooms catchment, showing the criteria and sub-criteria. G: = the relative importance or contribution of the criterion or sub-criterion to the whole model (scaled from 0 to 1); L: = the local contribution i.e. at that level in the hierarchy (scaled from 0-1).

6.3 IDENTIFICATION AND SELECTION OF DATASETS TO USE FOR THE CRITERIA AND SUB-CRITERIA

The structure, criteria and sub-criteria used in this model (Figure 31) are very similar to those used for the Karatara model (Figure 16), the main difference being the exclusion of the lakes because there are no lakes in this catchment.

The first set of criteria and sub-criteria in the hierarchy is aimed at prioritising the areas that are important for water source protection and increasing water quantity and for protection of aquatic ecosystems. The runoff was interpolated from a datasets on the mean annual runoff and then estimated for each compartment. The compartments were divided into those that included riparian (buffered) or wetland areas and the upland areas (Table 7). The runoff gains from clearing upland areas are typically lower per unit area than those from riparian or wetland areas, but the upland invasions are typically much more extensive so the overall gains in runoff are greater. The last set focuses on protecting biodiversity. Fire regime information was derived from datasets on fires, and conservation priorities and threatened ecosystems from CapeNature's Biodiversity Spatial Plan (Pool-Stanvliet et al., 2017) datasets.

Table 7: The criteria or sub-criteria and the datasets used to derive the necessary values

Criterion or sub-criterion	Datasets used as the source and the priorities
Mean annual runoff (mm)	Mean annual runoff dataset as used for the surface water Strategic Water Source Areas (Le Maitre et al., 2018; Nel et al., 2017) bilinearly interpolated to a grid of 250x250 m to align with the grid used for the National Invasive Alien Plant Survey (Kotzé et al., 2010). Calculated per compartment using the *ArcGIS* version 10, Spatial Analyst zonal statistics tool. Areas with the greatest MAR get the highest priority

Riparian and wetland areas	The best estimate of the original extent of the river and wetland areas in the Keurbooms catchment is the areas mapped as "Sources" and "Drains" for the Garden Route Initiative vegetation map (Vlok et al., 2008). They do not cover the entire catchment so the upper part of the Keurbooms River in quaternary K40A was added from the national river dataset used for the NBA 2018 (Skowno et al., 2019; Van Deventer et al., 2018). We extracted the riparian and wetland areas, overlaid them on the management compartments and calculated what proportion of each compartment was riparian/wetland or upland. The proportion of each compartment which was riparian or upland was multiplied by the MAR to generate the weights used in the prioritisation. Water flow regulation by wetlands is mainly a function of the occurrence and extent of valley bottom and river floodplain wetlands within a catchment. The wetlands of these types within the catchment were extracted from the NWM5 (van Deventer et al., 2020), the wetlands dataset created for the 2018 National Biodiversity Assessment (Skowno et al., 2019). The Keurbooms catchment is geomorphologically rugged, characterised by markedly incised rivers with generally narrow floodplains and quite steep gradients. These conditions result in very limited situations where waterflow-regulating floodplain wetlands (e.g. palmiet) can develop. The NWM5 dataset (van Deventer et al., 2020) shows that such wetlands only occur along main stem of the Palmiet River in the eastern part of quaternary K60D. This river has been severely degraded by *Acacia mearnsii* invasions and could be restored to palmiet wetlands. The selected wetland areas were overlaid on the compartments to work out the proportion of each compartment with these types of wetlands.
Maintain fire regime	Current vegetation age derived from: (a) CapeNature's All Fires coverage for 2018 -19 for veld age (available from the Biodiversity GIS (https://www.sanbi.org/link/bgis-biodiversity-gis/) for their Protected and Mountain Catchment Areas; and (b) MODIS burnt area dataset converted to the days since the last fire for areas not included in the CapeNature dataset (data extracted from the Advanced Fire Information System database housed at the CSIR). The area-weighted mean post-fire age was calculated for each compartment. Top priority is given to clearing areas approaching an ecologically acceptable age for burning or older than that.
Biodiversity conservation priorities and National Parks Expansion	Cape Nature's Biodiversity Spatial Plan Handbook (Pool-Stanvliet et al., 2017) datasets on vegetation type threat status, Critical Biodiversity Areas (CBAs) type 1 and 2, and Ecological Support Areas 1 and 2 (downloaded from the B-GIS https://www.sanbi.org/link/bgis-biodiversity-gis/). Highest priority goes to CBAs, which include all remnants of threatened vegetation types. The Garden Route National Parks Expansion Areas dataset was provided by Johan Baard (personal communication, March 2020).

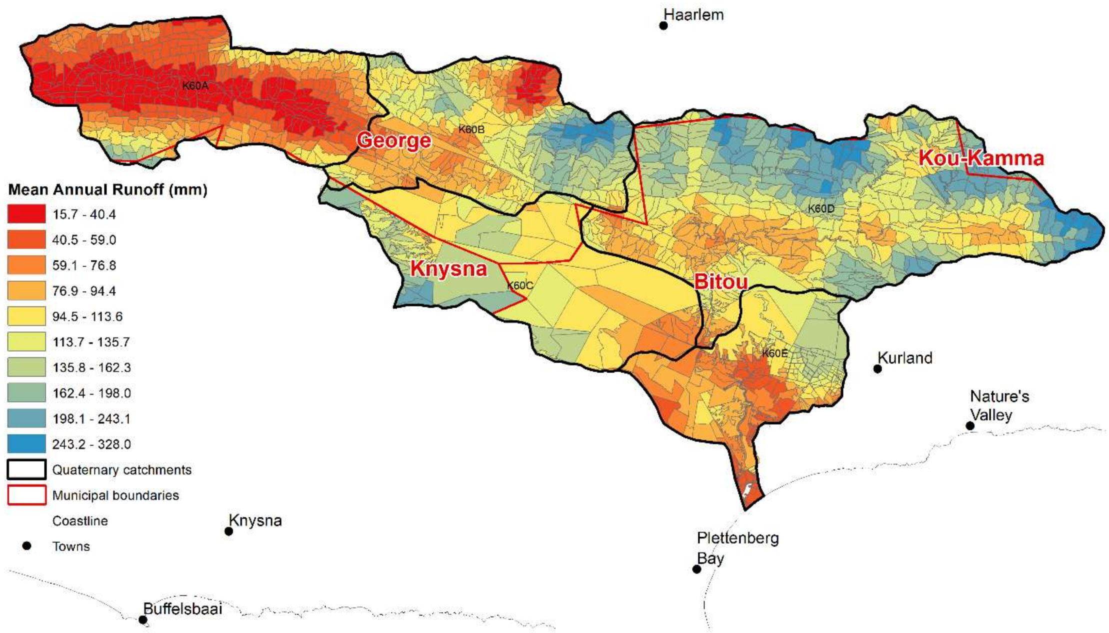

Figure 32: Mean annual runoff per compartment in the Keurbooms catchment. For more information, see Table 7.

The highest mean annual runoff in the Keurbooms catchment is in the Langkloof Mountains in the north of the catchment, which form the eastern extension of the Tsitsikamma (Figure 32). The southern part of the catchment and the western part are characterised by relatively low rainfall. Overall, this is a relatively dry catchment compared with the Karatara, and especially the Holsloot. Most of the MAR is generated in quaternaries K60B and K60D that are the primary source of the water for the rapidly developing holiday town of Plettenberg Bay.

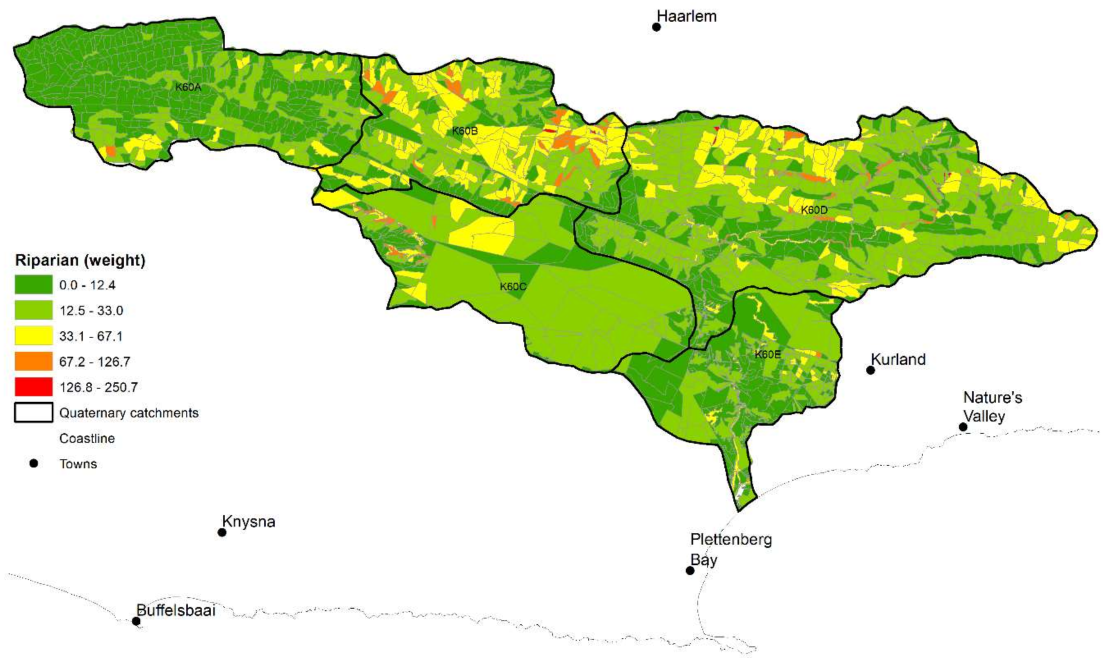

Figure 33: Compartments with riparian areas based on the GRI vegetation map's riparian areas. The weight is based on the riparian proportion times the MAR for that compartment so that the weight includes the MAR. For more information, see Table 7.

The AHP prioritisation model included the mean annual runoff (MAR) and below it two criteria, giving weights to clearing riparian versus upland areas (Figure 31). The best way to accommodate this hierarchical structure was to use the proportion that was riparian and multiply it by the MAR. The fully riparian compartments (red shade) are not evident because they comprise the narrow river floodplains that cannot be seen at this spatial resolution.

The same approach was used with the upland proportion of each compartment and, in this case, the high values closely track the spatial pattern of the MAR (Figure 32) which will focus clearing investments in these areas. The priority given to the upland areas was higher than that for the riparian areas, so upland areas will have a greater influence on the overall priorities.

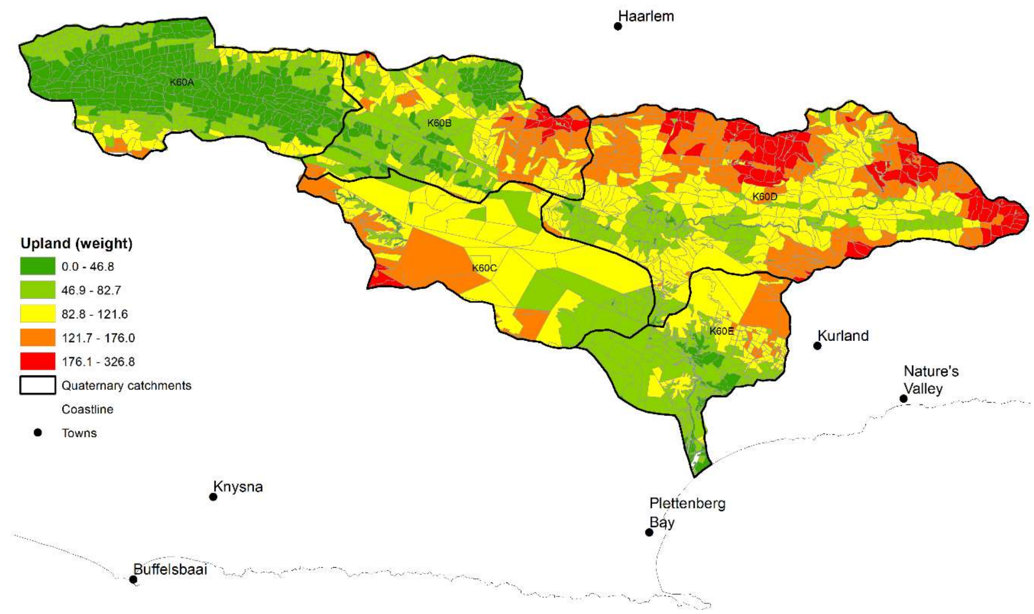

Figure 34: Compartments with a high proportion of upland areas based on the GRI vegetation map's riparian areas. The weight is based on the riparian proportion times the MAR for that compartment so that the weight includes the MAR. For more information, see Table 7.

The biodiversity conservation priorities are concentrated in two areas of the catchment: (a) the Langkloof Mountains, much of which falls within the Garden Route National Park; and (b) a corridor linking this area to the coast and mouth of the Keurbooms River. Quaternary catchment K60C has the fewest areas with a high weight for biodiversity conservation largely because little of the area falls within protected areas or is a high priority for biodiversity conservation.

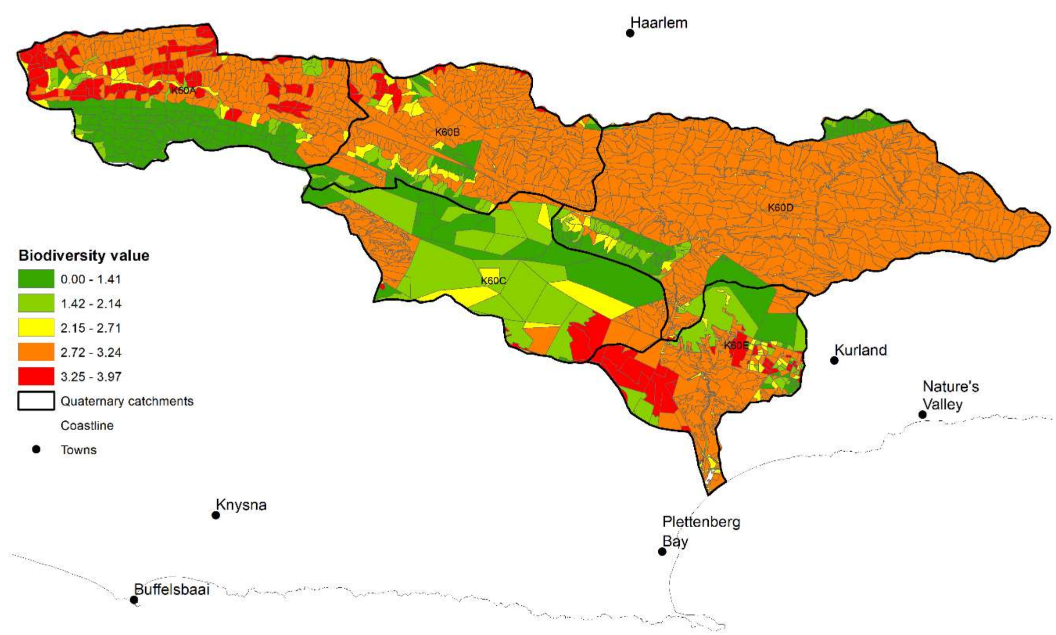

Figure 35: Biodiversity protection priorities including the protected areas. For more information, see Table 7.

Much of the veld in the catchment is less than 7.2 years of age, especially in the southern portion of the catchment (Figure 36). Much of the catchment is a complicated mosaic of veld ages, with only a small proportion being of an ecologically acceptable age for burning (>10-12 years old). This is unlike the Karatara where a large proportion of the catchment had not burnt for at least 30 years.

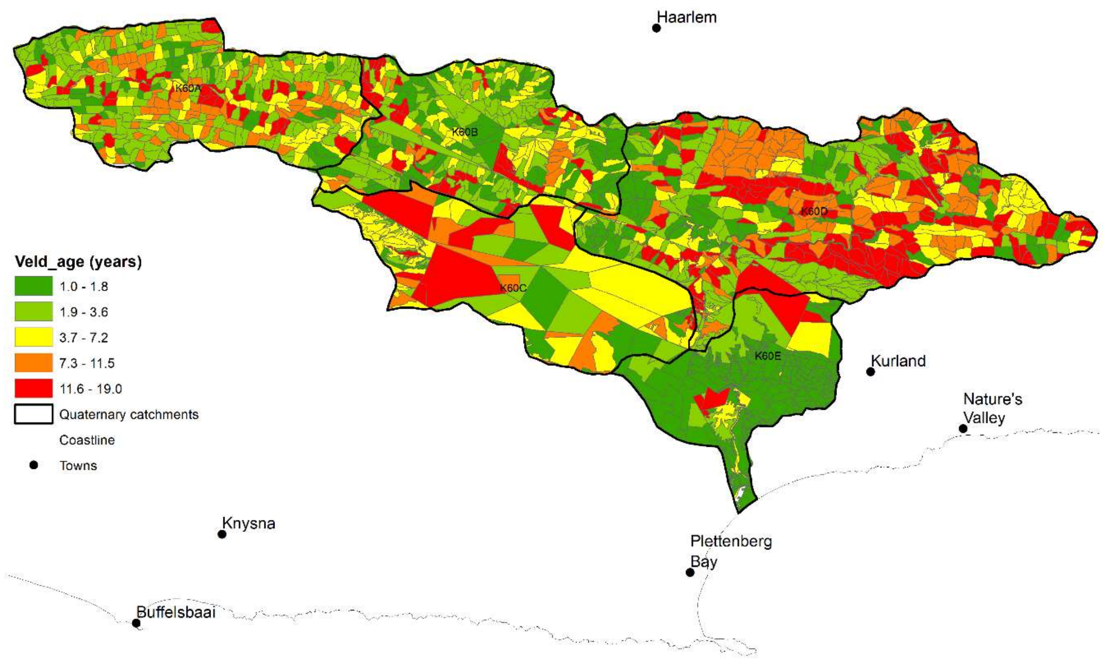

Figure 36: Mean post-fire veld age in the Keurbooms River catchment. For more information, see Table 7.

6.4 DATASETS USED IN THE CREATION OF THE COMPARTMENTS, MAPPED INVADED UNITS AND NBALS

The MUCP tool requires datasets for the management units (compartments), all known or mapped invasions and treated areas (i.e. NBALs) (Table 8)

Table 8 The basic spatial datasets required by the MUCP tool, data sources and processing.

Spatial dataset & attributes	**Source datasets and data processing**
Compartments	SANParks management compartments dated March 2020 as supplied by Johan Baard (personal communication), CapeNature's mini-compartments (supplied by CapeNature), a compartment dataset developed for Natural Resource Management programmes (Department of Forestry, Fisheries and Environmental) for use for planning, including the MUCP tool, and cadastral data from the Surveyor General (National Geo-spatial Information system) as supplied by Andrew Wannenburgh. Ideally, compartments take account of natural features as well as administrative boundaries (cadastres). Riparian compartments were selected using those that included or adjoined rivers extracted from the database used for the National Biodiversity Assessment (Skowno et al., 2019).
Mapped Invaded Units	All the mapped invasion data that could be used including the attribute data in CapeNature's mini-compartment dataset for

	their protected areas. We also obtained an update of the mapping of invasions done for the Garden Route Initiative in 2008 (Vromans et al., 2010) prepared by Paul Buchholz in 2018. This information was combined with the NBAL data (see below) to give as complete a coverage as possible (Figure 37).
Treated invaded units (NBALs)	Data for treated areas supplied by Andrew Wannenburgh (NRM programmes) from the WIMS database; the records for the most recent treatment contract were taken as representing the current state. NBALs that had not been followed-up for 5 years or more were considered untreated and merged with the MIU information.

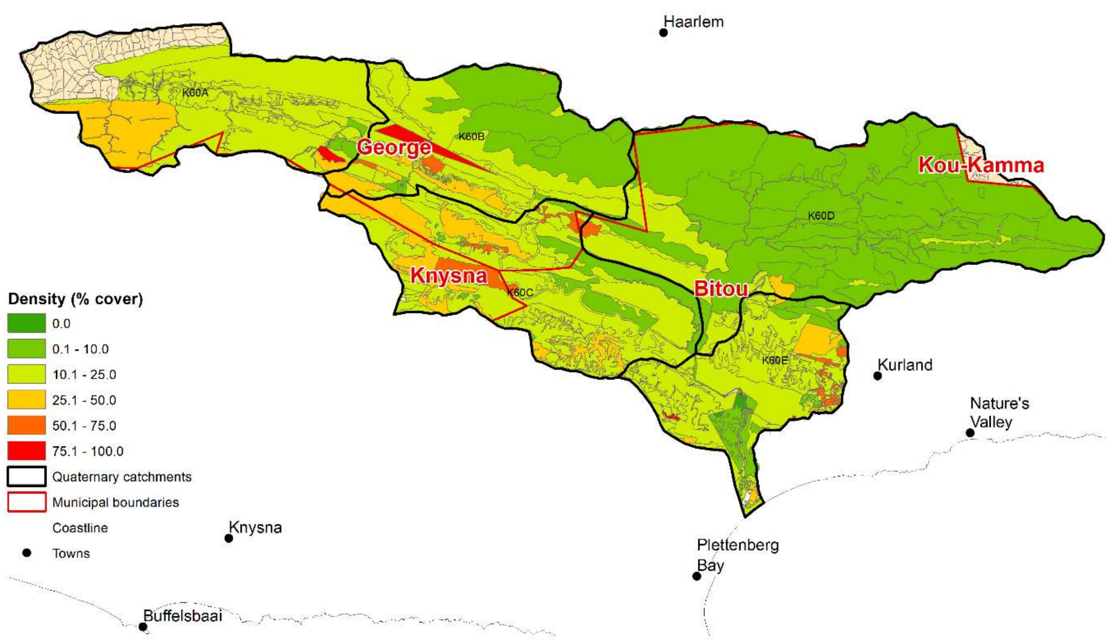

Figure 37: The density of the invasions in the compartments of the Keurbooms catchment. For more information, see Table 8.

6.5 PRIORITIES ESTIMATED USING THE AHP MODEL

The values for each compartment for each of the variables which represents each of the criteria and sub-criteria in the model were extracted and compiled in a spreadsheet. The export Grid option in the software was used to create a spreadsheet template into which the values for each compartment (alternative) could be copied. The values from this prioritisation dataset were copied to the correct columns in the template spreadsheet. The completed template was then imported into the AHP grid and loaded into the software for processing. The resulting priorities are shown below.

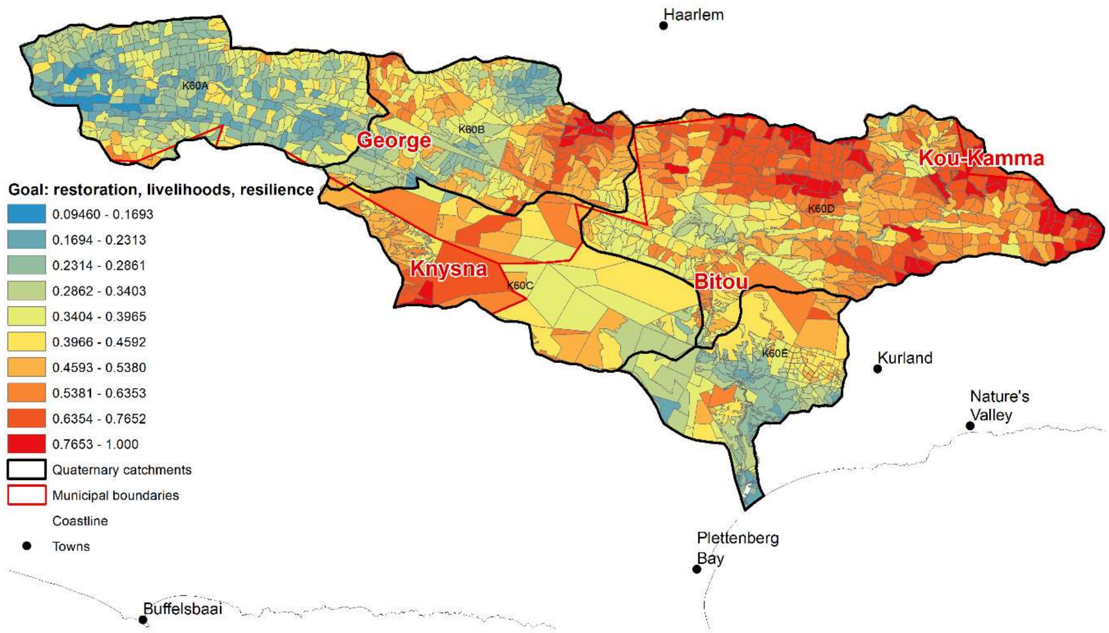

Figure 38: The Keurbooms catchment showing the priority values for each management compartment based on the overall goal as defined in AHP model (Figure 31), and the values for each compartment of each of the variables in the model.

The compartments prioritised for the goal are closely aligned with the distribution of the areas with high MAR in the catchment in quaternaries K60D, K60C and the eastern part of K60B. A number of the priorities for restoration (biodiversity protection) have also been highlighted, including areas within quaternary K60E. Although rivers and wetlands (versus uplands) and wetland restoration for water quality are included, wetland types that could have an important role in water quality are located only in a few places in the catchment and the priorities are more strongly influenced by the spatial distribution of the MAR.

This map also highlights the very large number of compartments that have been defined. With such high numbers of compartments is it hard to identify the top 5 or 10 in the map but they can be extracted from the multi-criteria model.

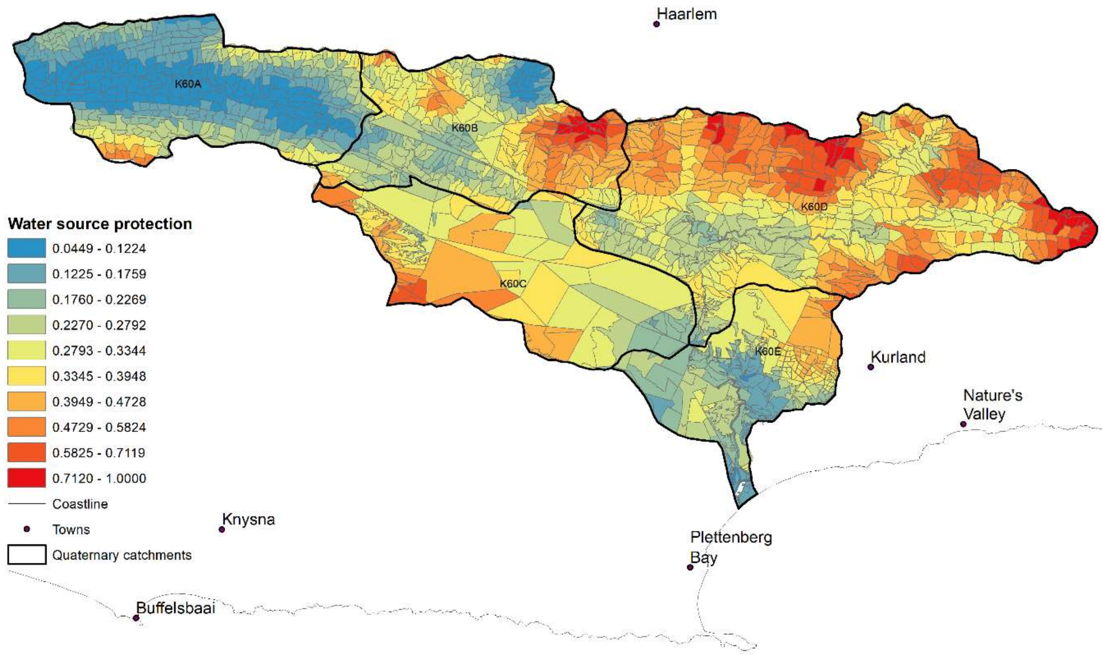

Figure 39: The Keurbooms catchment showing the priority values for each management compartment based on water source protection as defined in AHP model (Figure 31), and the values for each compartment of each of the variables in the model.

The spatial distribution of the priorities for water source protection is similar to that for the goal, but with a greater concentration of the priorities in areas with a high MAR. Rivers and wetlands occur in all the catchments, according to the vegetation map (Vlok et al., 2008), so they play a relatively limited role in determining the priorities. Wetland types that regulate water quality occur only in the main course of the Palmiet River in the eastern part of K60D and have little influence on the priorities.

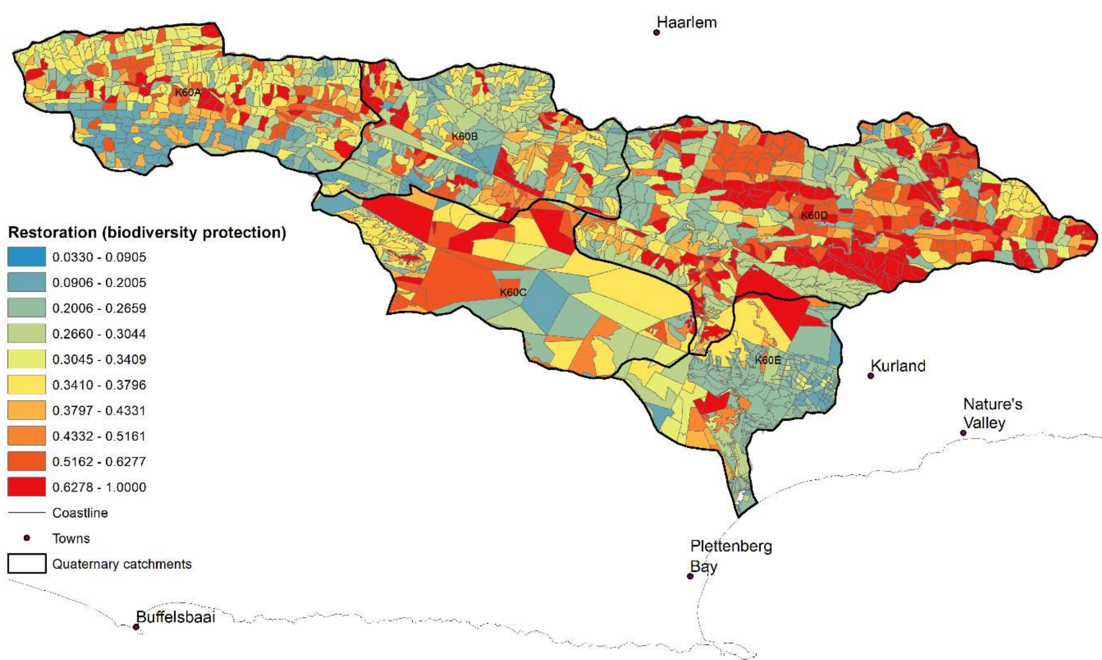

Figure 40: The Keurbooms catchment showing the priority values for each management compartment based on restoration of functional landscapes (biodiversity conservation) as defined in AHP model (Figure 31), and the values for each compartment of each of the variables in the model.

The restoration priorities are scattered throughout the catchment, with a concentration in quaternary K60D, which is almost entirely inside the Garden Route National Park. The distribution of the priorities is strongly influenced by the occurrence of areas of fynbos of a suitable age for burning. Another set of priorities is located in areas adjacent to the existing protected areas that are earmarked for park expansion (e.g. western part of K60C. These compartments include areas identified as priorities in CapeNature's Biodiversity Spatial Plan (Pool-Stanvliet et al., 2017).

6.6 OUTPUTS OF THE MUCP TOOL: PRIORITIES AND RESOURCE REQUIREMENTS

The MUCP system generates a number of outputs, most of which are best viewed using the facilities in the system (e.g. the maps generated by the Visualisation section) or by exporting the datasets to spreadsheets (e.g. the treatment schedules and budgets). *We have presented these outputs here but have to state, again, that we have low confidence in these outputs because of the low confidence we have in the data on alien plant invasions. This in turn will lead to poor estimates of the resources required to bring the densities down to acceptable levels and of the potential gains in river flows. The Keurbooms catchment has more than 2600 compartments, which also makes checking of the input data a time consuming task.*

There is general alignment between the priorities generated for the goal and for water production by the multi-criteria AHP model (Figure 38, Figure 39) and the outputs of the MUCP system (Figure 41). The top priorities are all located in quaternary catchment K60D which is in line with it having the greatest MAR (Figure 32). A key influence was the weighting of the Upland compartments (Figure 34). The location of the lower level priorities is also influenced by the biodiversity protection priorities (Figure 40), as was the case with the priorities for the other two MUCPs.

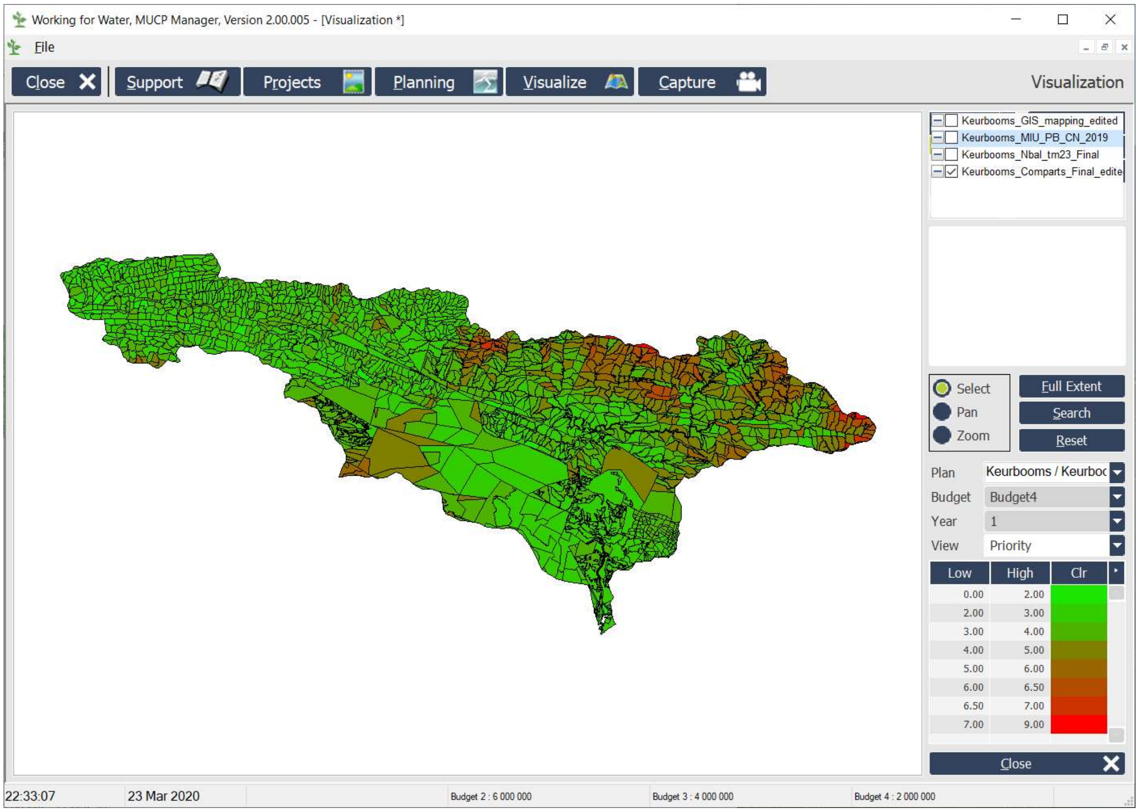

Figure 41: The spatial distribution of the priorities for the different compartments in the Keurbooms catchment.

This summary of the compartment information shows that only one of the top 14 compartments has any invasions, and that all of them are located in the high runoff areas of quaternary catchments K60B and K60D ()Figure 42. As noted previously, they may be uninvaded or a reflection of the poor quality data in this area. Given poor state of the Soetkraal area in K60D, as described in conversations with various people with knowledge of the area, we are inclined to believe that this is more due to poor quality mapped data. This screen shows that the optimal budget for clearing in year 1 would be about R8.6 million and the treatments would require more than 31 000 person days. Since budgets 1 and 2 were R15 and R10 million respectively, the resources required for year 1 would be the same as the optimal (Figure 43). Budget 3 of R5 million would be fully allocated as would budget 4 of R2.5 million. The gains in water flows (decreases in reductions) over time show that most of the gains would be made in the first year (Figure 45). The budget allocations to catchments are to those located mostly in the lower lying areas of the catchment where there are very large compartments (Figure 46), but some are in protected areas managed by CapeNature or SANParks, and in the planned GRNP expansion areas. The allocations change substantially when the budget is reduced to R2.5 million, which allows for the treatment of a few, limited areas (Figure 47).

*As noted above, we must emphasise that our confidence in these outputs is low, especially considering how markedly they differ from values derived from the National Invasive Plant Survey data from 2007 (*Table 6*). We are still assessing the invasion data that we have had to use, so these figures are likely to be revised.*

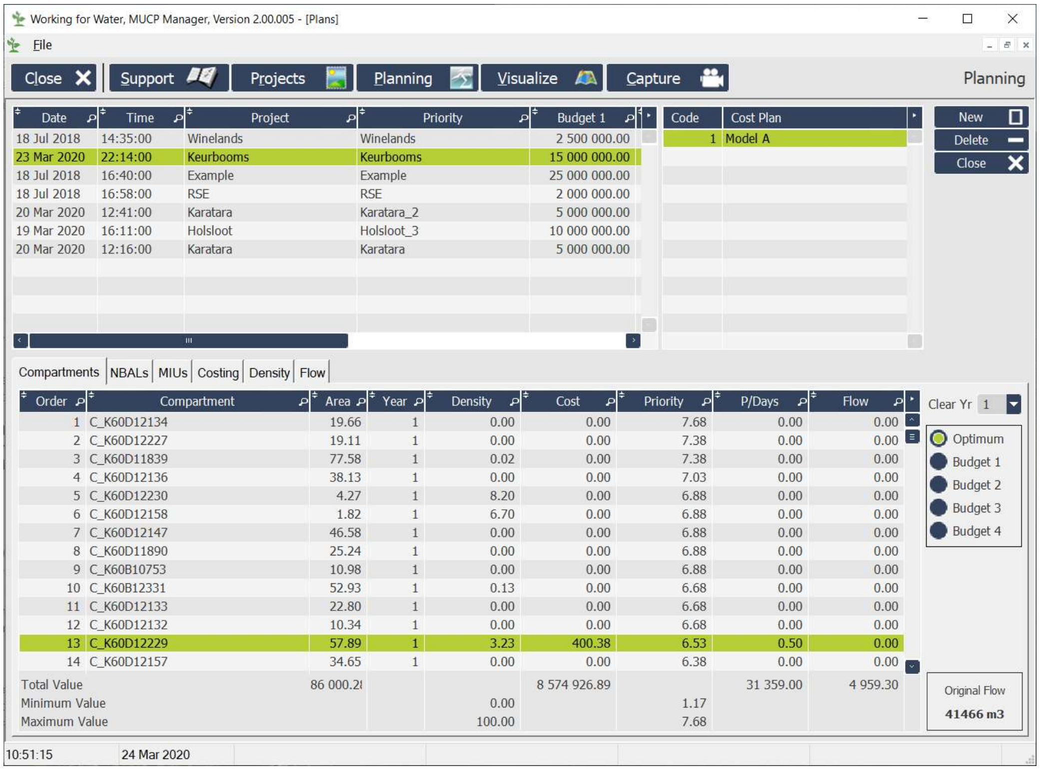

Figure 42: A summary of the Compartment information displayed under the compartment tab in the planning part of the system.

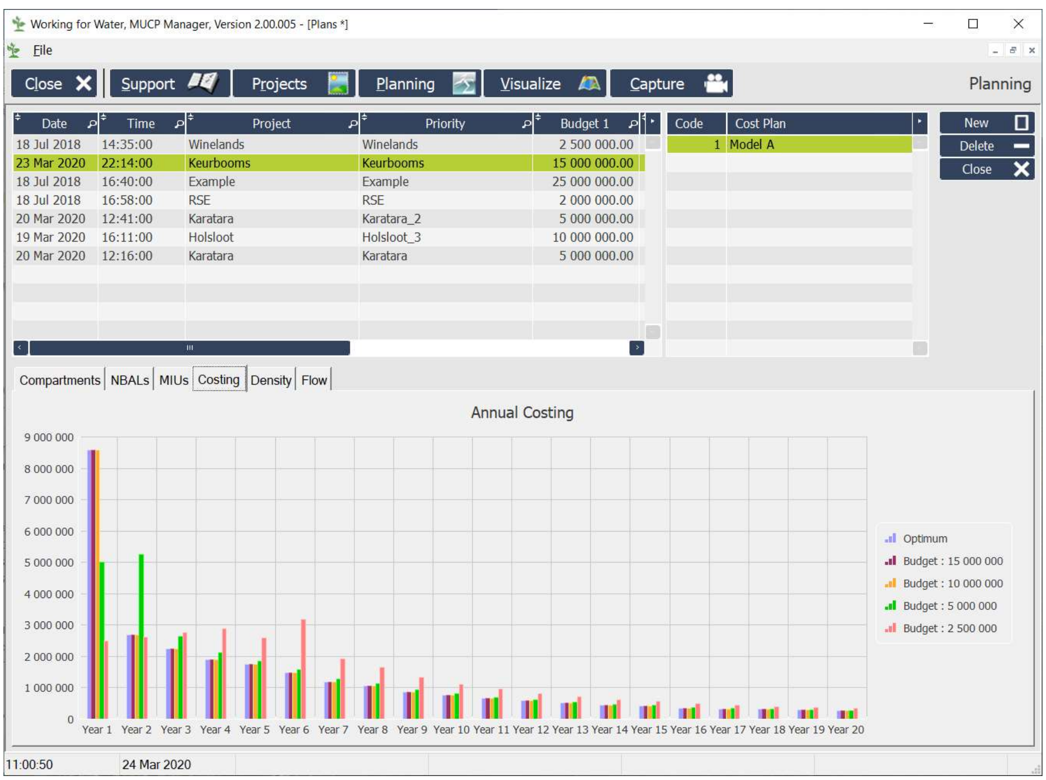

Figure 43: The information displayed when the Costing tab is selected showing the planned annual budgets for different budget ceilings over the 20 year planning horizon used by the MUCP system. The budgets all escalate at 6% per year to allow for inflation.

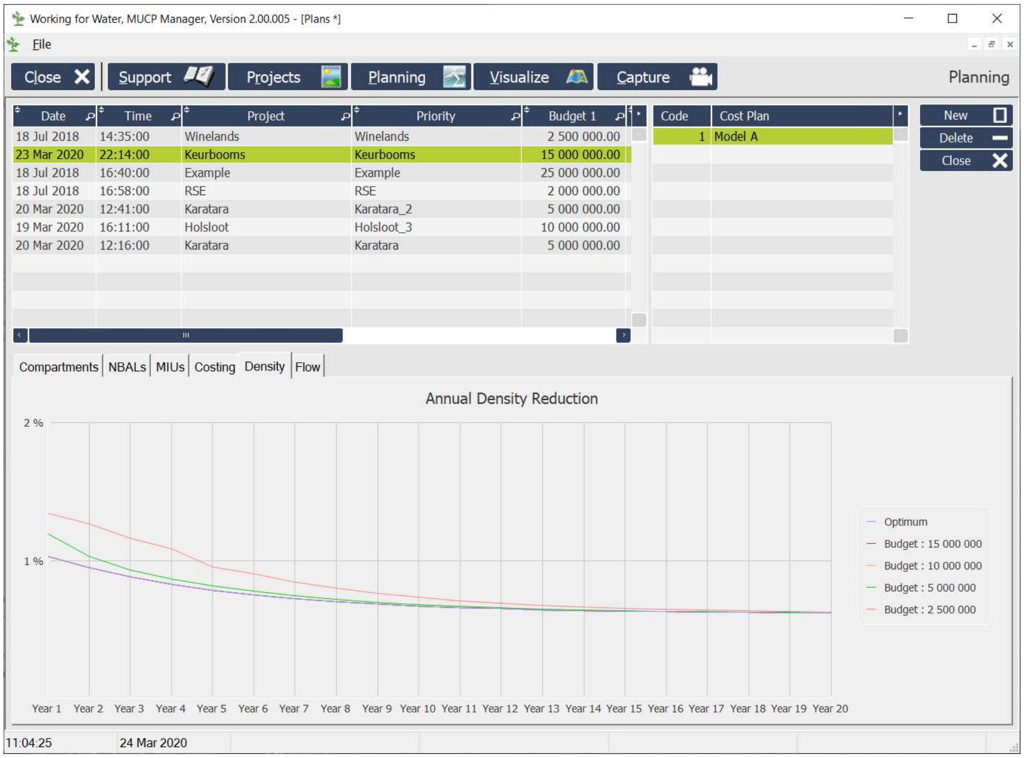

Figure 44: The information shown under the Density tab is showing the projected reduction in the density of invasions for different budget ceilings over the 20-year planning horizon used by the MUCP system.

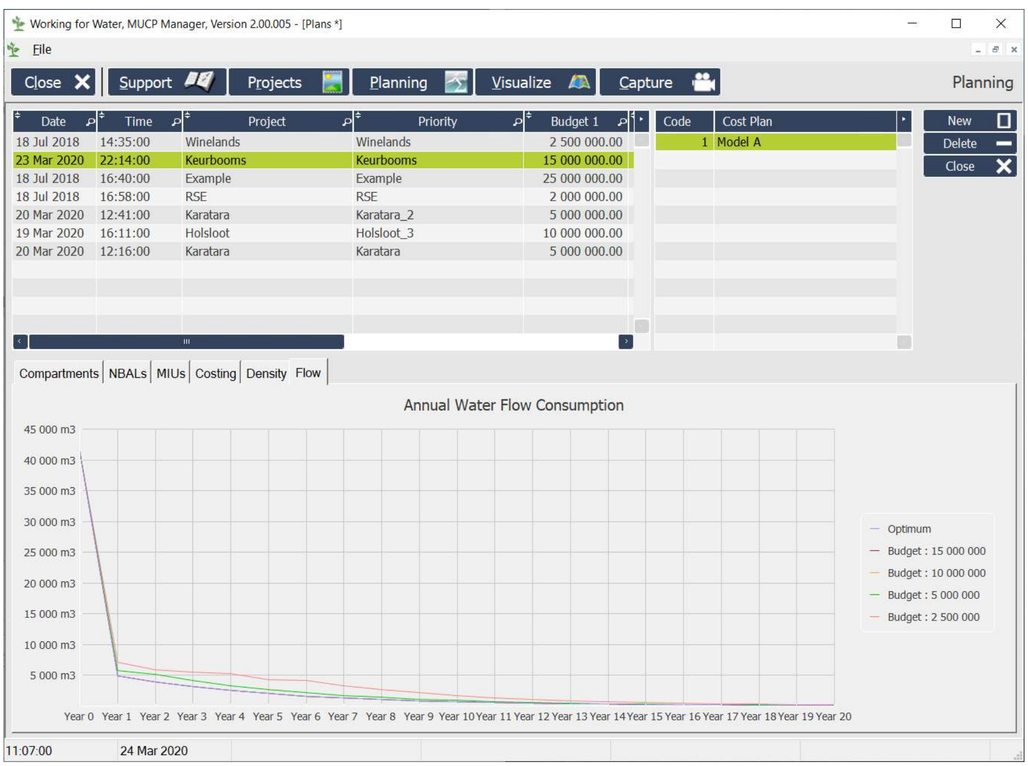

Figure 45: The projected decline in the annual water flow consumption (i.e. the additional amount of water used each year by the invading plant species) for each planned budget over the 20-year planning time-frame.

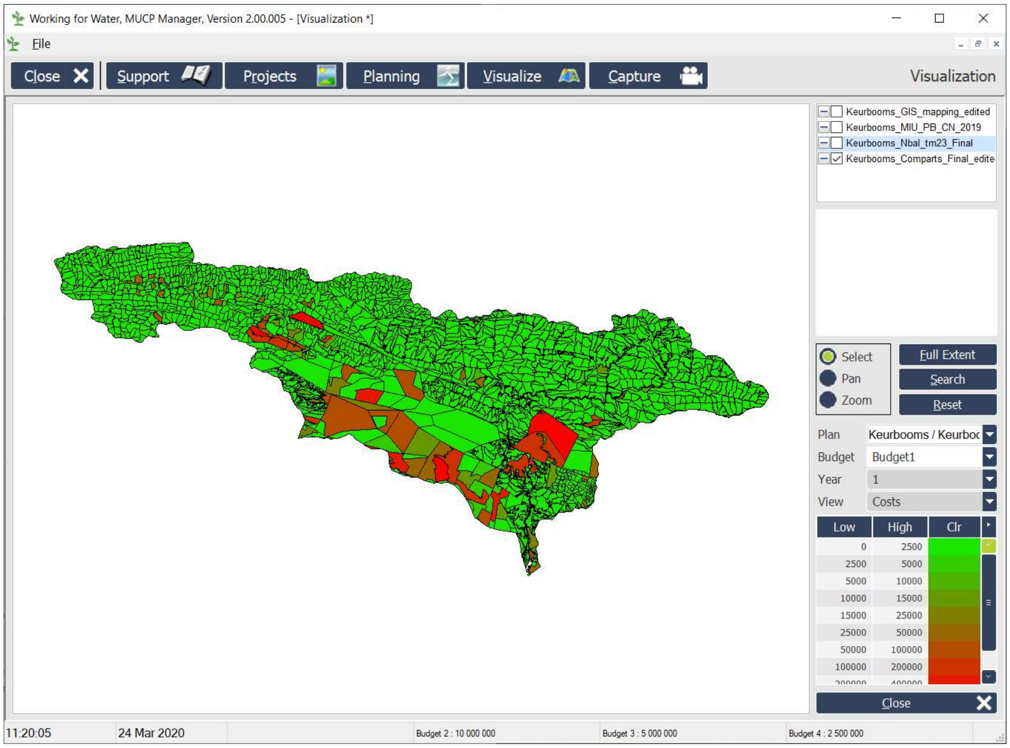

Figure 46: The budget allocations for the different compartments in the Keurbooms catchment for year 1 and Budget 1 of a maximum of R15 million of which only R8.6 million is spent (Figure 42).

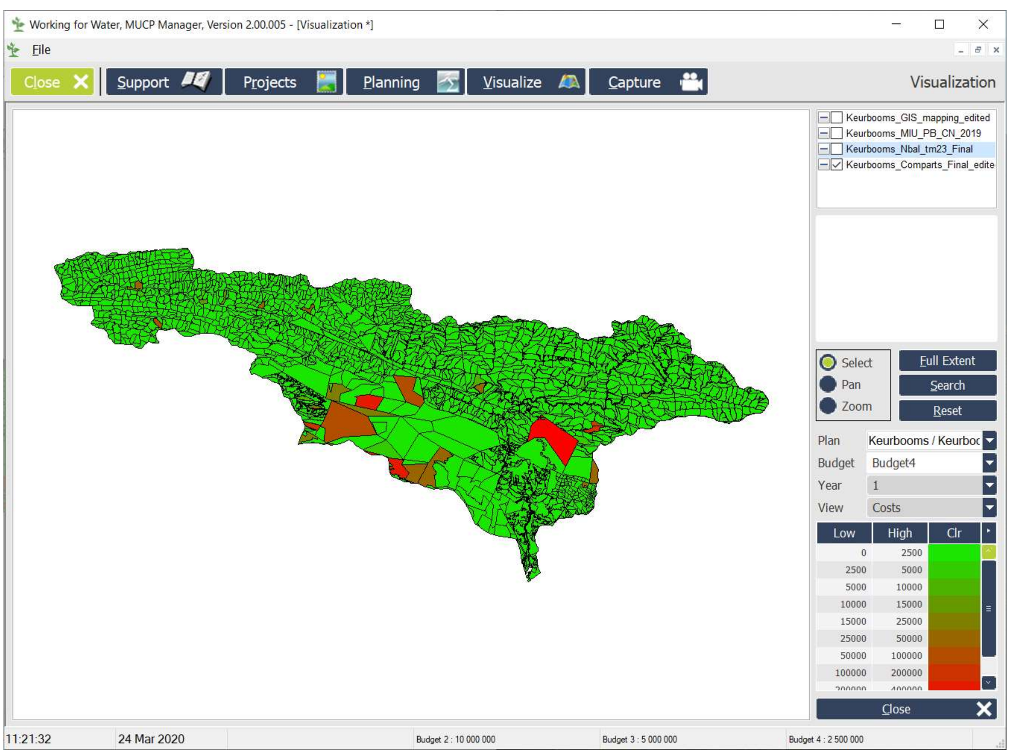

Figure 47: The budget allocations for the different compartments in the Keurbooms catchment for year 1 and Budget 1 of a maximum of R2.5 million.

7 Some points to note about the MUCP system

The MUCP system is already a useful tool, as we have demonstrated in this report. It enables partners and other stakeholders to get an idea of the resources they will require to clear an area within a given time-frame. However there are a number of important considerations and limitations that need to be taken into account.

- The system does not have rules that change the stage of the invasion as successive treatments are applied. It is able to calculate how densities reduce over time from the different species' treatment density reduction factors but there are no rules which change the age. So, for example, a stand of mature pines will remain mature and will not change to seedling or young as successive treatments are applied. The costs will continue to be calculated for the mature species and the densities are assumed to be reduced, which they may not be where species have large seed banks. In some cases this will result in an overestimate of the costs, in others an underestimate. The fact that the state does not change also affects the estimates of much water is released (i.e. the decrease in the water flow reduction). There are ways to correct this but they must still be implemented.
- The costs that are generated are a combination of the treatment norms (e.g. person days per ha) and the cost per person day for people as well as running costs. It is important for the users to try to estimate these costs as accurately as possible because inaccurate costs at the hectare level can have a significant impact on the costs at the catchment level. The basic cost model is quite simple but the users can add additional daily costs to customise the cost mode further. These additional costs may be weekly or monthly but can be converted to daily by dividing them by the number of working days in that period.
- The density of the invasions is reduced according to a density reduction factor. The system calculates the percentage of the initial density and then subtracts that from the original density. It also does not continue treating areas once they have reached the so-called maintenance level, usually about 1% cover.
- At present, the MUCP system does not allow for the use of fire as a treatment measure. However, much of this catchment is invaded by pines and hakea, whose follow-up costs can be significantly reduced by combining treatments with prescribed burning. Effective use of fires will reduce the treatment costs over time for this catchment, and the total budget will be much lower than is estimated by the MUCP system.

Some difficulties we have encountered which have slowed the creation of these MUCPs:

- The most important issue that we encounter is poor quality data on the alien plant species invasions with inaccurate mapping, incorrect species and inaccurate estimation of the densities and age classes. This applies both to the compilation of data on all the invaded areas and those portions of the invasions that have been treated. High quality and accurate data are required for the generation of realistic estimates of the resources required to complete the treatment programme. Time spent on ensuring that the data are good quality is well spent.
- Another critical dataset is the management compartments. The NRM programmes (Working for Water) have a project that is delineating such compartments at the quaternary catchment level. This is very useful where it exists and it does include protected areas where they are part of a quaternary catchment. However, many of the protected area agencies already have their own management compartments and trying to align the two along the protected area boundaries is time consuming. At

present the NRM compartment datasets (shapefiles) do not include the slope, drive and walk times.

- Where there are no pre-defined compartments, and parts of the planning domain fall outside protected areas, we have had to use the cadastral data from the National Geospatial Information system. These data are very poor quality with numerous gaps between adjacent polygons and duplicate polygons. Cleaning up these data sets, even partially, is very time consuming.

8 NEXT STEPS

The models will still be shared with the participants to ensure that they are in agreement with the results (i.e. priorities) and training provided so that they understand and can use the software. We will be doing this in the new financial year once the travel restrictions, imposed because of the risks posed by the virus causing Covid-19, are lifted sufficiently for us to travel and hold small meetings.

There are many examples of multi-stakeholder projects where having champions, people who will drive the process, is the key to their success. The workshop participants need to identify champions to take forward the implementation of these plans. Implementing these plans will require negotiations among the participants and a strong champion can help move things forward as rapidly as possible. It is vital that all the participants are kept fully informed of developments and work together to secure sufficient resources to implement the plan.

The plans for the Keurbooms and the Karatara catchments also need to be assessed in the context of the proposed PES projects (DEA&DP, 2018a), and any progress that has been made on the PES initiative since the project report was compiled. The value that these MUCPs bring to the PES process is that they provide information on the likely costs and duration of the clearing programme, as well as indicating the areas that are deemed the highest priority to clear.

The MUCP plans as presented here should not be seen as set in stone, They will require regular updates. A strong champion can play a critical role in getting the updated data from those involved in the clearing and updating the input to the tools so updated plans can generated. Our experience has also shown that when unexpected events, such as fires, occur, it is relatively straightforward to revise the information on the existing invasions of that area to reflect what they will be after the fire based on their experience or of experts that they can consult. Once that has been done, they can then re-run the model to see what the new treatment schedules and resource allocations will be.

We have tried to illustrate the kinds of options and considerations that the partners and stakeholders in the clearing of the catchment can evaluate when assessing the resources required for the clearing and the resources they have available or can secure. We believe that this emphasises the value of using the MUCP system to the users.

9 BIBLIOGRAPHY

Bailey, A.K., Pitman, W. V, 2015. WR2012 Study User's Guide Version 1. Water Resources of South Africa 2012 Study (WR2012). Report K5/2143/1, Water Research Commission, Pretoria.

BGCMA, 2015. Breede-Overberg Catchment Management Strategy. Breede-Gouritz Catchment Management Agency, Worcester.

BolandEnviro, 2016. Proposed weir and diversion works, Holsloot River, Rawsonville. DEADP Ref 16/3/3/1/B2/21/1047/16, Department of Envionmental Affairs and Development Planning, Western Cape Goverment, Cape Town.

DEA&DP, 2019. Western Cape Provincial Ecological Infrastructure Investment Framework: Catchment Prioritisation Report. Prepared by the CSIR for the Western Cape Government: Department of Environmental Affairs and Development Planning (DEA&DP), Cape Town.

DEA&DP, 2018a. Business Case for the Keurbooms and Karatara River Catchments. Final version submitted for approval, October 2018. Department of Environmental Affairs and Development Planning, Western Cape Government, Cape Town.

DEA&DP, 2018b. Western Cape Sustainable Water Management Plan 2017 — 2022. Towards a new norm for water resilience. Depertment of Environmental Affairs & Development Planning, Western Cape Government, Cape Town.

DEA&DP, 2017. Environmental Resources Protection Plan for the Breede River Catchment in the Western Cape. Department of Environmental Affairs and Development Planning, Western Cape Government, Cape Town.

DWS, 2014. Development of Reconciliation Strategies for All Towns in the Southern Planning Region; George. Version 2 April 2014. Department of Water and Sanitation, Pretoria.

Dzikiti, S., Gush, M.B., Le Maitre, D.C., Maherry, A., Jovanovic, N.Z., Ramoelo, A., Cho, M.A., 2016. Quantifying potential water savings from clearing invasive alien Eucalyptus camaldulensis using in situ and high resolution remote sensing data in the Berg River Catchment, Western Cape, South Africa. For. Ecol. Manage. 361, 69–80. https://doi.org/10.1016/j.foreco.2015.11.009

Dzikiti, S., Schachtschneider, K., Naiken, V., Gush, M., Le Maitre, D., 2013. Comparison of water-use by alien invasive pine trees growing in riparian and non-riparian zones in the Western Cape Province, South Africa. For. Ecol. Manage. 293, 92–102.

Everson, C.S., Clulow, A.D., Becker, M., Watson, A., Ngubo, C., Bulcock, H., Mengistu, M., Lorentz, S., Demlie, M., 2014. The long term impact of Acacia mearnsii trees on evaporation, streamflow, low flows and ground water resources. Phase II: Understanding the controlling environmental variables and soil water processes over a full crop rotation. Report No. 2022/1/13, Water Research Commission, Pretoria.

Fill, J.M., Forsyth, G.G., Kritzinger-Klopper, S., Le Maitre, D.C., van Wilgen, B.W., 2017. An assessment of the effectiveness of a long-term ecosystem restoration project in a fynbos shrubland catchment in South Africa. J. Environ. Manage. 185, 1–10. https://doi.org/10.1016/j.jenvman.2016.10.053

Forsyth, G., Le Maitre, D., van den Dool, R., Walls, R., Pharaoh, P., Fortune, G., 2019. The Knysna fires of 2017: Learning from this disaster. A collaborative research report between Santam, the University of Stellenbosch and CSIR. Supported by the Western Cape Disaster Management Centre. Santam, Bellville.

Forsyth, G.G., Le Maitre, D.C., O'Farrell, P.J., van Wilgen, B.W., 2012. The prioritisation of invasive alien plant control projects using a multi-criteria decision model informed by stakeholder input and spatial data. J. Environ. Manage. 103, 51–57.

Frost, P.E., Kleyn, L.G., van den Dool, R., Burgess, M., Vhengani, L., Steenkamp, K., Wessels, K., 2018. The Elandskraal Fire, Knysna. A data driven analysis. Meraka Institute, CSIR, Pretoria.

Gelderblom, C., Le Maitre, D., McKelly, D., van der Heyden, F., Chapman, A., van Wilgen, B., Robyntjies, R., Carelse, L., van Wyk, E., Burns, K., Rowlinson, L., Sulaiman, A., 1997. Management plan for alien vegetation in the Riviersonderend Catchment. A. Main report. B. Appendices.

Kotzé, I., Beukes, H., van den Berg, E., Newby, T., 2010. National Invasive Alien Plant Survey. Report No. GW/A/2010/21, Agricultural Research Council – Institute for Soil, Climate and Water, Pretoria.

Kraaij, T., Baard, J.A., Rikhotso, D.R., Cole, N.S., van Wilgen, B.W., 2017. Assessing the effectiveness of invasive alien plant management in a large fynbos protected area. Bothalia 47. https://doi.org/10.4102/abc.v47i2.2105

Kruger, F.J., 1977. Invasive woody plants in Cape fynbos with special reference to the biology and control of Pinus pinaster, in: Proceedings of the Second National Weeds Conference of South Africa. Weed Society, pp. 54–74.

Le Maitre, D.C., Forsyth, G.G., Dzikiti, S., Gush, M.B., 2013. Estimates of the impacts of invasive alien plants on water flows in South Africa. Report No. CSIR/NRE/ECO/ER/2013/0067/B, Natural Resources and the Environment, CSIR, Stellenbosch.

Le Maitre, D.C., Gush, M.B., Dzikiti, S., 2015. Impacts of invading alien plant species on water flows at stand and catchment scales. AoB Plants 7, plv043. https://doi.org/10.1093/aobpla/plv043

Le Maitre, D.C., Kotzee, I.M., O'Farrell, P.J., 2014. Impacts of land-cover change on the water flow regulation ecosystem service: Invasive alien plants, fire and their policy implications. Land use policy 36, 171–181. https://doi.org/http://dx.doi.org/10.1016/j.landusepol.2013.07.007

Le Maitre, D.C., Seyler, H., Holland, M., Smith-Adao, L., Nel, J.L., Maherry, A., Witthüser, K., 2018. Identification, Delineation and Importance of the Strategic Water Source Areas of South Africa, Lesotho and Swaziland for Surface Water and Groundwater. Final Integrated Report on Project K5/2431, Water Research Commission, Pretoria.

Le Maitre, D.C., van Wilgen, B.W., Richardson, D.M., 1993. A Computer System for Catchment Management: Background, Concepts and Development. J. Environ. Manage. 39. https://doi.org/10.1006/jema.1993.1059

McConnachie, M.M., Cowling, R.M., van Wilgen, B.W., McConnachie, D.A., 2012. Evaluating the cost-effectiveness of invasive alien plant clearing: A case study from South Africa. Biol. Conserv. 155, 128–135. https://doi.org/10.1016/j.biocon.2012.06.006

Nel, J.L., Le Maitre, D.C., Roux, D.J., Colvin, C., Smith, J.S., Smith-Adao, L.B., Maherry, A., Sitas, N., 2017. Strategic water source areas for urban water security: Making the connection between protecting ecosystems and benefiting from their services. Ecosyst. Serv. 28, 251–259. https://doi.org/10.1016/j.ecoser.2017.07.013

Nel, J.L., Murray, K.M., Maherry, A.M., Petersen, C.P., Roux, D.J., Driver, A., Hill, L., Van Deventer, H., Funke, N., Swartz, E.R., Smith-Adao, L.B., Mbona, M., Downsborough, L., Nienaber, S., 2011. Technical Report for the National Freshwater Ecosystem Priority Areas project. WRC Report No. 1801/2/11, Water Research Commission, Pretoria.

Pool-Stanvliet, R., Duffell-Canham, A., Pence, G., Smart, R., 2017. Western Cape Biodiversity Spatial Plan Handbook 2017. CapeNature and Department of Environmental Affairs and Development Planning, Western Cape Government, Cape Town.

Rebelo, A.G., Boucher, C., Helme, N., Mucina, L., Rutherford, M.C., Smit, W.J., Powrie, L.W., Ellis, F., Jan, J.N., Scott, L., Radloff, F.G.T., Steven, D., Richardson, D.M., Ward, R.A., Procheş, Ş.M., Oliver, E.G.H., Manning, J.C., Mcdonald, D.J., Janssen, J.A.M., Walton, A., Roux, A., Skowno, A.L., Simon, W., Hoare, D.B., 2006. Fynbos Biome, in: Mucina, L, Rutherford, M C (Eds.), The Vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19. South African National Biodiversity Institute, Pretoria, pp. 52–219.

Rebelo, A.J., Emsens, W.-J., Meire, P., Esler, K.J., 2018. The impact of anthropogenically induced degradation on the vegetation and biochemistry of South African palmiet wetlands.

Wetl. Ecol. Manag. 26, 1157–1171. https://doi.org/10.1007/s11273-018-9638-3

Richardson, D.M., Van Wilgen, B.W., Le Maitre, D.C., Higgins, K.B., Forsyth, G.G., 1994. A Computer-Based System for Fire Management in the Mountains of the Cape Province, South-Africa. Int. J. Wildl. Fire 4, 17–32. https://doi.org/10.1071/WF9940017

Schachtschneider, K., 2016. Breede Catchment Water Stewardship Programme – Summary report. World Wide Fund For Nature, South Africa.

Seeliger, L., Horn, A., Kloppers, W., 2018. Breede River environment plan taking shape. Water Wheel April, 22–25.

Skowno, A.L., Poole, C.J., Raimondo, D.C., Sink, K.J., Van Deventer, H., Van Niekerk, L., Harris, L.R., Smith- Adao, L.B., Tolley, K.A., Zengeya, T.A., Foden, W.B., Midgley, G.F., Driver, A., 2019. National Biodiversity Assessment 2018: The status of South Africa's ecosystems and biodiversity. Synthesis Report. South African National Biodiversity Institute, an entity of the Department of Environment, Forestry and Fisheries, Pretoria.

Van Deventer, H., Smith-Adao, L., Mbona, N., Petersen, C., Skowno, A., Collins, N.B., Grenfell, M., Job, N., Lötter, M., Ollis, D., Scherman, P., Sieben, E., Snaddon, K., 2018. South African Inventory of Inland Aquatic Ecosystems (SAIIAE). Report Number: CSIR report number CSIR/NRE/ECOS/IR/2018/0001/A; SANBI report number SANBI/NAT/NBA2018/2019/Volx/A, South African National Biodiversity Institute, Pretoria.

van Deventer, H., van Niekerk, L., Adams, J., Ketelo Dinala, M., Gangat, R., Lamberth, S.J., Lötter, M., Mbona, N., MacKay, F., Nel, J.L., Ramjukadh, C.-L., Skowno, A., Weerts, S.P., 2020. National Wetland Map 5: An improved spatial extent and representation of inland aquatic and estuarine ecosystems in South Africa. Water SA 46, 66–79. https://doi.org/10.17159/wsa/2020.v46.i1.7887

van Wilgen, B.W., Fill, J.M., Baard, J., Cheney, C., Forsyth, A.T., Kraaij, T., 2016. Historical costs and projected future scenarios for the management of invasive alien plants in protected areas in the Cape Floristic Region. Biol. Conserv. 200, 168–177. https://doi.org/10.1016/j.biocon.2016.06.008

van Wilgen, B.W., Forsyth, G.G., Le Maitre, D.C., Wannenburgh, A., Kotzé, J.D.F., van den Berg, E., Henderson, L., 2012. An assessment of the effectiveness of a large, national-scale invasive alien plant control strategy in South Africa. Biol. Conserv. 148, 28–38. https://doi.org/10.1016/j.biocon.2011.12.035

Van Wilgen, B.W., Govender, N., Forsyth, G.G., Kraaij, T., 2011. Towards adaptive fire management for biodiversity conservation: Experience in South African National Parks. Koedoe 53, a982. https://doi.org/10.4102/koedoe.v53i2.982

Vlok, J., Euston-Brown, D., Wolf, T., 2008. A vegetation map for the Garden Route Initiative. Unpublished 1:50 000 maps and report supported by CAPE FSP task team. Prepared by Regalis Environmental Services for the Garden Route Initiative.

Vromans, D.C., Bradshaw, P.B., Holness, S.D., 2010. The Garden Route Critical Biodiversity Areas (CBA) Mapbook. The Garden Route Biodiversity Sector Plan. Supporting land-use planning and decision making in Critical Biodiversity Areas and Ecological Support Areas for sustainable development. SANParks. Knysna.

Wilgen, B.W. Van, 2012. Evidence, Perceptions, and Trade-offs Associated with Invasive Alien Plant Control in the Table Mountain National Park, South Africa. Ecol. Soc. 17. https://doi.org/10.5751/ES-04590-170223

Wilgen, B.W. Van, Forsyth, G.G., 2008. The historical effects and future management of fire regimes in the fynbos protected areas of the Western Cape province.

Appendix 1: Attendance registers