# ECOLOGICAL FUNCTIONALITY OF THE UPPER AND MIDDLE VAAL WATER MANAGEMENT AREAS

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## ABSTRACT

*A harmonised in-stream water quality guideline was constructed for the Upper and Middle Vaal Water Management Areas (WMAs) using ideal catchment background values for the sub-catchments; Vaal dam, Vaal barrage, Klip River and Blesbokspruit/Suikerbosrant Rivers. Data for years 2003 to 2009 was interpolated to a daily time-step for 2526 days at 21 monitoring sites covering both WMAs. Conductivity was used as a surrogate to capture the variability in water quality. This provided an ecological functionality model of the study area, coded for ranges 10-18, 19-45, 46-80, 80< and 81-100 mS/m.*

*The Upper and Middle Vaal basin is currently extremely vulnerable to changes in water quality, uncertainty about changes which it can tolerate, and the fact that there are very limited options for mitigating effects of poor water quality in the basin, overall. Thus a precautionary approach is being proposed in this paper, in order to protect the ecological functionality of the aquatic ecosystem. The proposed harmonised guideline presents a crucial model to pre-determine the ecological functionality for any water point in the study area, in order to provide upstream-downstream pollution trading and other decision support processes towards sustainable basin management*

## INTRODUCTION

The VR is not only an important source of raw water for industrial, agricultural and domestic use within Gauteng and the lower VR; it is also one of the prime recreational sites of Gauteng. In its conclusion, a report by DWAF (1) notes that eutrophication had become a major threat to the VR water quality, with the non-complying wastewater treatment plants distorting the nitrogen and phosphorus cycling in the river system. This study documents background and literature relating to the first objective of the study, which was formulated as follows:

*To apply pollutant tracer hydrochemistry in order to determine the ecological functionality of specific reaches of the Upper and Middle VR and to produce an integrated ecological functionality (IEF) for the study area*

Self-purification mechanisms are thus vital for continuity of the existing micro and macro living organisms in the VR system. Further, various metal and non-metal constituents discharged for example from mining effluents (2) have direct toxic effects at elevated levels. They also carry the potential of causing serious variations on existing ecosystems in the receiving waters. These conditions affect the self-purification mechanisms.

**River health status**

A river system may be utilised by humans, for example for recreation, irrigation and as a source of potable water. Utilisation of water resources will inevitably result in some impacts and modification of the resource and needs managing and regulating so as to try and maintain its integrity. An aquatic system may possess natural thresholds to the extent and frequency of change it can tolerate without being irreversibly altered. However, it may also have certain limits beyond which it is difficult to recover or regain its functional capacity without mitigation like levying polluters heavily for discharging waste into water courses that are classified as good quality water sources.

While practically all effluent is expected to be treated and returned to natural water courses in order to obtain maximum utilisation of scarce water resources, return effluent containing pollutants affects the quality of the receiving waters. An important concern is the ultimate effect of shifts in water quality on riverine ecosystem functioning.

Determining the ecological functionality of the water resource serves to provide information that could be used to determine the degree to which water quality might be altered through the return of effluent, and other impacts, without compromising the health of aquatic ecosystems.

**Fitness for use**

Management of water resources quality is a complex issue affected in the main by several sub-processes like hydrological, hydraulic, chemical, biological and ecological processes which are so far not thoroughly explicable (3). It is vital then for decision-makers and water quality managers to have sound scientific norms and guidelines for effective communication relating to water quality complaints with regards to water pollution. Further, it is equally important to dialogue with raw water users regarding the economic costs of using water of variable quality.

A common basis from which to derive water quality objectives is the essential requirement that enables key stakeholders in such a complex system to act in harmony in order to achieve the overarching goal of maintaining the fitness of water for specific uses and to protect the health of aquatic ecosystems.

Water quality can affect water uses or the health of aquatic ecosystems in many different ways. For example, it can affect the health of an individual drinking the water or swimming in it, productivity or yield of a crop being irrigated. Further, cost of treating water before it can be used for example in industrial process and for potable use, and the sophistication of technology for treating that water to adequate quality, are among parameters used to differentiate the various requirements for different user groups.

In some instances the requirements may even conflict. These differences imply that water which would be adequately fit for use in one instance might not be suitable for another, although water seldom becomes totally unfit for use when the quality deteriorates. Quality is thus not an intrinsic property of water, but is linked to the use made of that particular water.

A definition of what constitutes fitness for use is then a key issue in the evaluation and management of the quality of water resources. The process of deriving quality criteria and associated management guidelines for freshwater ecosystems has a long history in South Africa (4). Several different approaches have been proposed and evaluated. The development of South African water quality guidelines was essentially to derive a set of water quality criteria to safeguard freshwater ecosystems in South Africa.

It is necessary though, to use a number of yardsticks when making judgement about the fitness for use of water, especially as DWAF (4) acknowledges that guidelines are not static and will therefore be updated and modified on a regular basis, determined by ongoing research and review of local and international information on the effects of water quality on water uses and aquatic ecosystems

Aquatic ecosystems are vulnerable to changes in water quality, uncertainty about changes which they can tolerate, and the fact that there are very few options for mitigating the effects of poor water quality. A precautionary approach is therefore required to protect the ecological functionality of aquatic ecosystems. Measures should be taken to avert or minimise potential risks of undesirable impacts. Part of the precautionary approach is to minimise risk to the system in all the decision-making steps involved in water quality management.

Planktonic algae occupy a central position in the eutrophication picture in lakes and it is these plants which are considered here, with special reference to British waters. They are less important in rivers except in the larger, richer or slow-flowing ones used for water supply. However, the effects of nutrient enrichment on higher plants and the alga Cladophora (blanket weed) should not be underestimated, especially in rivers and shallow standing waters. The chemical element most commonly considered to be the major cause of eutrophication is phosphorus, though it is obviously an over-simplification to consider one element alone without reference to the many other environmental factors controlling the growth of plants and animals. The other main elements are thought to be nitrogen and carbon (5).

Eutrophication of surface water bodies has been linked to several water quality problems, including fish kills and harm to wildlife as a result of reduced oxygen content of eutrophic water caused by death and decay of algae. Eutrophication restricts fisheries, recreational, and industrial water uses, as well as increases the health hazards related to the formation of carcinogens during chlorination of drinking water (6).

During transport in overland flow and in-stream channels, a complex and dynamic interaction between dissolved organic phosphorus (DOP), particulate phosphorus (PP) and sediments takes place, where phosphorus (P) is transformed, deposited, sorbed, and desorbed. Mechanisms controlling P release, transport, and transformation are detailed in Khadam and Kaluarachchi (7).

**Targeting sewage pollution**

In recent years the focus of environmentalists and concerned residents near the VR barrage has shifted from the threat of industrial pollution to that of the threat of sewage pollution. The VR barrage remains primarily a storage facility of sewage and industrial waste water.(8). Experts point out that the country's local authorities are increasingly unable to cope with the constant demand for effective sewage treatment (8)

Municipalities in South Africa have a huge responsibility for water services operation. Since 1994 alone, they have received grant and loan funding to acquire more than R30 bn. of water services infrastructure (at construction cost; current replacement value would be more). The replacement value of pre-1994 water services infrastructure in their care is unknown, but almost certainly much larger. (R30 bn is of the order of US$5 000 m at 2010 exchange rates of about 1 USD to R6). Operating all of this has become the responsibility of municipalities or groups of municipalities in their role as the statutory water services authorities (WSAs).

In addition, a significant proportion of the South African population does not enjoy safe water and/or acceptable sanitation – this represents a huge responsibility for the construction of new infrastructure and, after its construction, its operation by municipalities. Even if all the existing institutional role-players were coping with the water services operational responsibility, there would be good reason to investigate alternative institutional concepts, on the grounds that it needs to be established whether alternatives to current (2010) funding mechanisms could be more cost-effective (9).

*Biogeochemical impacts*

Depending on its source, wastewater discharges in rivers are classified under three main types: domestic wastewater (those coming from a purifying plant which collect the water from an urban sewer system), industrial wastewater (those coming from an industrial plant), and agricultural wastewater (those coming from irrigation and fertilizing). Very strict legislative requirements for wastewater disposal in rivers have been established by the governments of developed countries, so that all wastewater discharged into a river must first be treated in a purifying plant, in order to reduce its pollutants levels.

Despite all these legal regulations, many of South Africa's rivers (or, specifically, several sections of these rivers) keep levels of pollutants higher than the allowed thresholds, since the rivers are not capable of assimilating all the wastewater disposed there.

The most common practice for remediation of these polluted river sections consists of the injection of a given amount of clear water from a reservoir in a nearby point. This strategy of flow regulation by means of reservoirs presents a high efficiency in order to purify polluted rivers in a short period of time. According to Alvarez-Vázquez *et al.* (10), the main challenge is (once the injection point is chosen by geophysical reasons) finding the minimum quantity of water to be injected into the river section for purification purposes. Considering the study area and the pollution sources, it might not be practical.

**Electrical conductivity, a surrogate indicator**

Water quality in a river is analyzed in terms of dissolved oxygen (DO) and biochemical oxygen demand (BOD), but always from a completely linear point of view, that is, the state system is a linearization of the shallow water equations, which avoids the main difficulties of the problem (10).

The increased threat of faecal pollution in recent years and the high priority of protecting human health by the government led to the initiation of a national microbial monitoring programme for surface water in South Africa. According to the design of the programme, monitoring sites had to be selected in order to assess the status and trends of faecal pollution. Issues of efficiency and cost-effectiveness dictated that the monitoring would focus on areas with the greatest risk.

According to Wepener *et al.* (11), relating observed effects of pollution to specific pollutants or even classes of pollutants remains a very difficult task due to the usually unknown, complex and often highly variable composition of effluents. Ochieng' (12) notes that total dissolved solids (TDS) provide an indication of salinity. Since TDS is not easily measured, it is common to utilise electrical conductivity (EC) multiplied by a correction factor of 0.7 to obtain TDS (13). Walton (13) also suggests using factors ranging from 0.50 to 0.75 for increasingly saline waters. Thus EC was used as a surrogate for tracing pollution in this study.

## METHODS AND MATERIALS

Pollutant tracer hydrochemistry was carried out for specific reaches of the U&MVWMAs in order to produce an IEF for the whole study area block diagrammed in Figure 1.

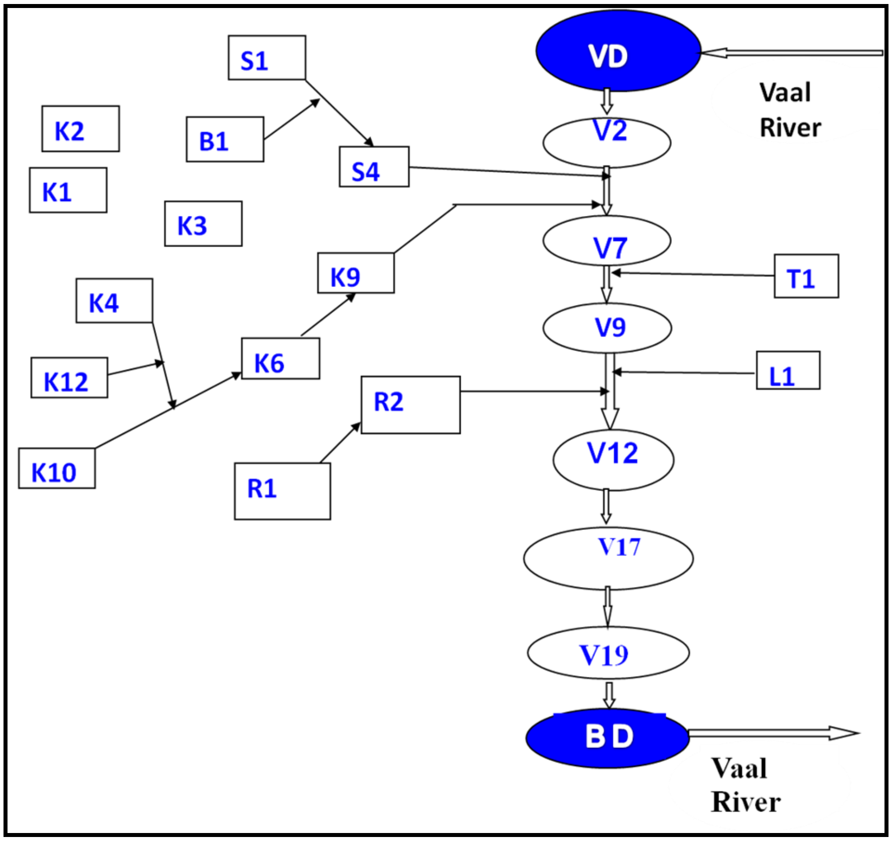
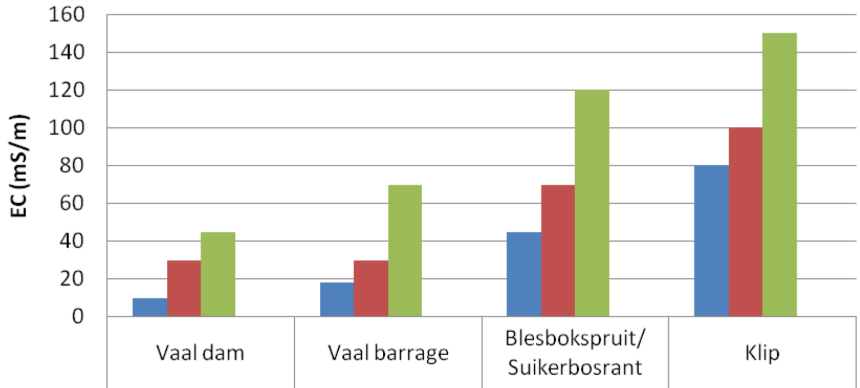


Figure 1: Block interrelationships of monitoring points

Results from this study would inform the development of models to classify the surface raw water as it varied temporally and spatially along the VR. An integrated quality-cost model would provide an invaluable water management pricing tool that correlates surface raw water quality variability to cost of treating that water to potable standard according to SANS 241:2006.

**Pollutant tracer hydrochemistry**

Use of EC as a surrogate for tracing pollution was informed by literature as well as availability of fairly consistent data for the period of study and for all study monitoring points. Daily interpolated EC values were compared to guideline values of the ideal catchment background (ICB) raw water quality objectives for VDICB, VBICB, BSICB and KICB (Figure 2), and applicable to the U&MVWMAs.




| | Vaal dam | Vaal barrage | Blesbokspruit/ Suikerbosrant | Klip |
|---|---|---|---|---|
| ICB | 10 | 18 | 45 | 80 |
| AMT | 30 | 30 | 70 | 100 |
| TIT | 45 | 70 | 120 | 150 |
| U | | | | |

Figure 2: Selected in-stream water quality objectives
Source: http://www.reservoir.co.za/ (accessed September 2008)

Values for VDICB -10 mS/m, VBICB - 18 mS/m, BSICB - 45 mS/m and KICB - 80 mS/m were used for comparing quality of raw water. Although national monitoring campaigns use sub-catchment-specific guidelines; this paper used the four ICBs as indicated in Figure 2 because it was felt that the approach provided a fair baseline for comparison within the study area, which covered more than one sub-catchment.

VR tributary entry points were employed to trace pollution by comparing their EC values to those at/or just downstream of a tributary's confluence with the VR main channel: S4 on SR, K9 on KR, T1 on TR, L1 on LR and R2 on RvR.

**Stacked EC against ICB guideline values**

The EC values were pre-processed into daily values for 1 January 2003 to 30 November 2009. Cubic interpolation was performed to fill in missing data and all stacked graphs were plotted using Matlab 2010b. The points V2, V17 and V19 represented Rand Water Board's potable water treatment intake works located in the UVWMA and intake works for Midvaal Water and Sedibeng Water Boards located in the MVWMA, respectively. EC trends for 2003-2009 for these WBs were also stacked among themselves and in relation to the ideal catchment background values.

## RESULTS AND DISCUSSION

ICB values were compared among themselves as in Figure 3. VDICB value was considered ideal for this study and thus provided the lower bound. KICB provided the upper bound, beyond which comparable values were above limit.

The following plots investigated impacts of pollution on the tributaries as well as on the VR. The plotting period (x-axis) represents daily interpolations for 2526 days, from 1 January 2003 to 30 November 2009.

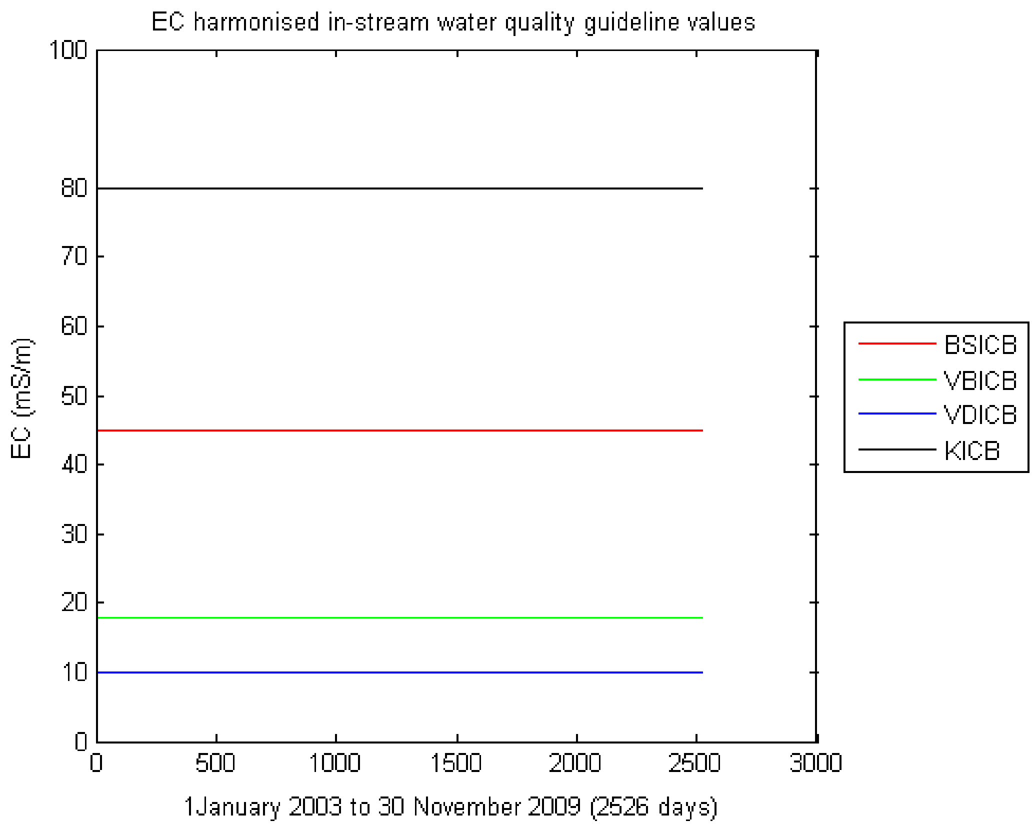
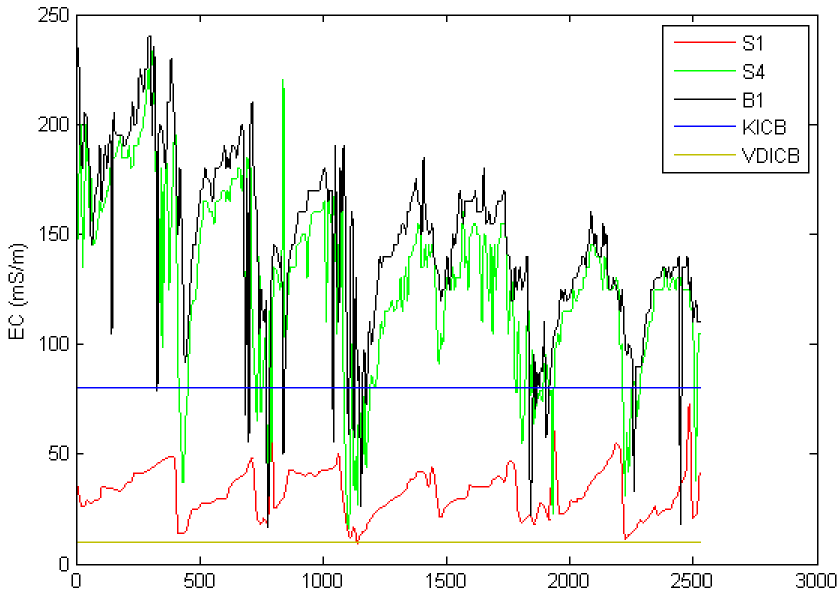



Figure 3: Harmonised guideline values

The EC data, as was all other data sets which were manipulated in this study, was interpolated to daily data to provide data of the same period.

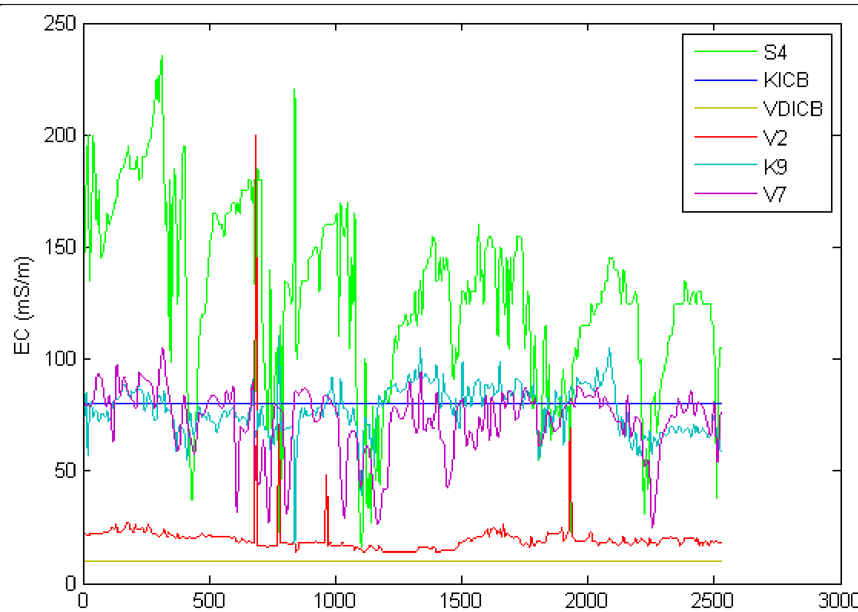
Figure 4 provides an indication of the impact of BR on SR. It was noted that before confluence of BR/VR, SR was well below the upper limit of KICB, although the values were variable over the period 2003 to 2009, from the spikes observed in the graph. In addition, BR impacted heavily on SR through B1. BR drained into SR as it transported polluted water from its upper reaches.

V2 values were found to be very close but above the VDICB as shown in Figure 5. When SR drained into VR through S4, VR values immediately spiked to the upper limit of KICB values at V7. This indicated that SR presented a huge impact on VR.




Day 1 to day 2526

Figure 4: Impact of BR on SR




Day 1 to day 2526

Figure 5: Impact of SR on VR

Figure 6 indicates that the mine dumps around RwR were having a huge impact on RwR through K2 and K4. The tributary points K1 and K3 values were within acceptable guideline values.

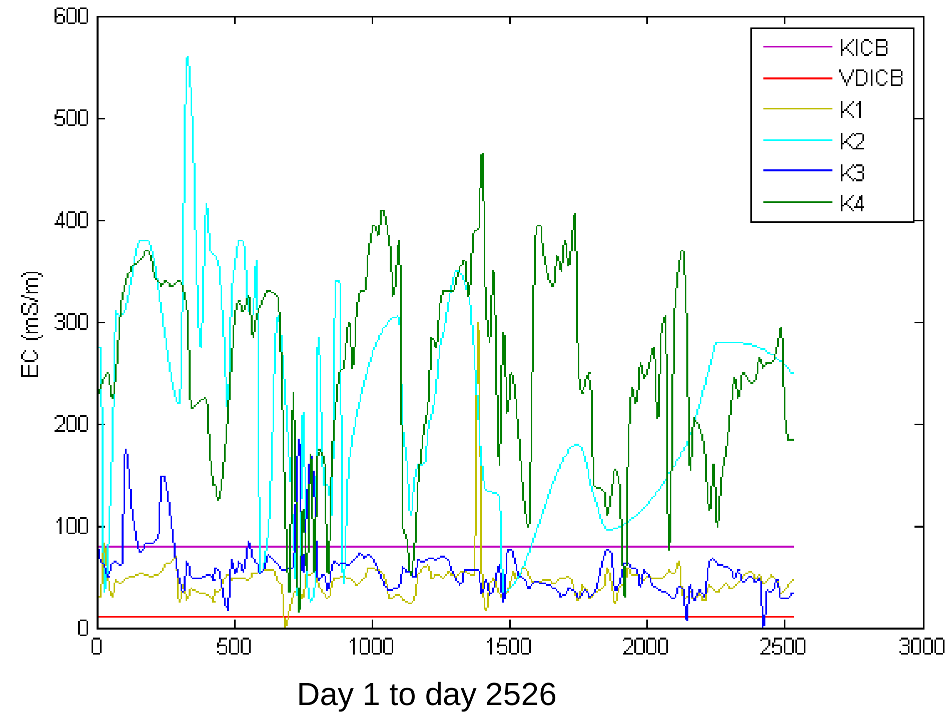
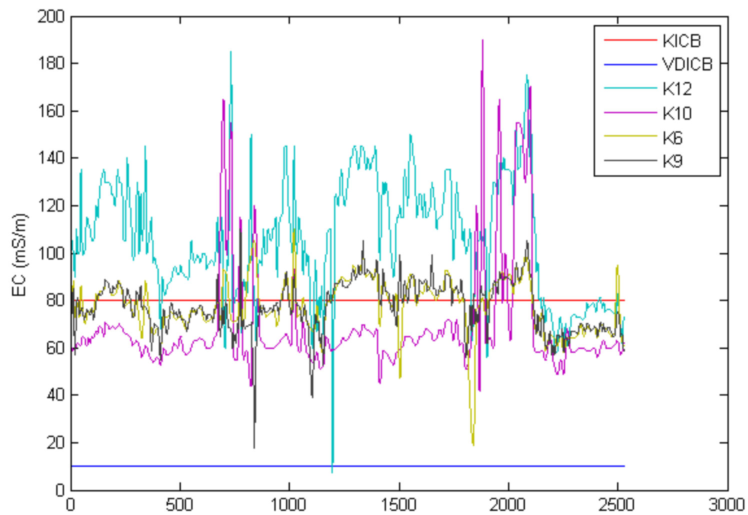



Figure 6: Variation of EC along RwR

In

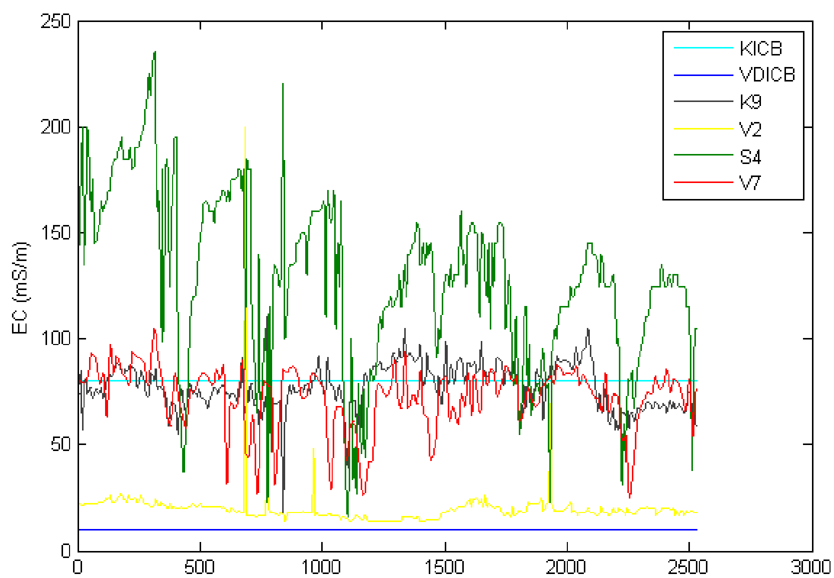
Figure 7, K12 EC was above limits but so was also that for K10 for some periods. Still, K12 was impacting negatively on KR. Using

Figure 8, it was noted that although KR was negatively impacting on VR through K9, a much greater impact on VR was being realised from SR through S4, where the EC values were way above the upper limit of the harmonised guideline values. This combined impact was being observed at V7 as that point experienced huge EC values when compared to V2 further upstream on VR.




Day 1 to day 2526

Figure 7: Impact of NR on KR




Day 1 to day 2526

Figure 8: Impact of KR on VR

Although values for T1as noted in

Figure 9, were higher than those for V7 and V9, the impact on VR was negligible.  All values generally played around the upper most limit of KICB.

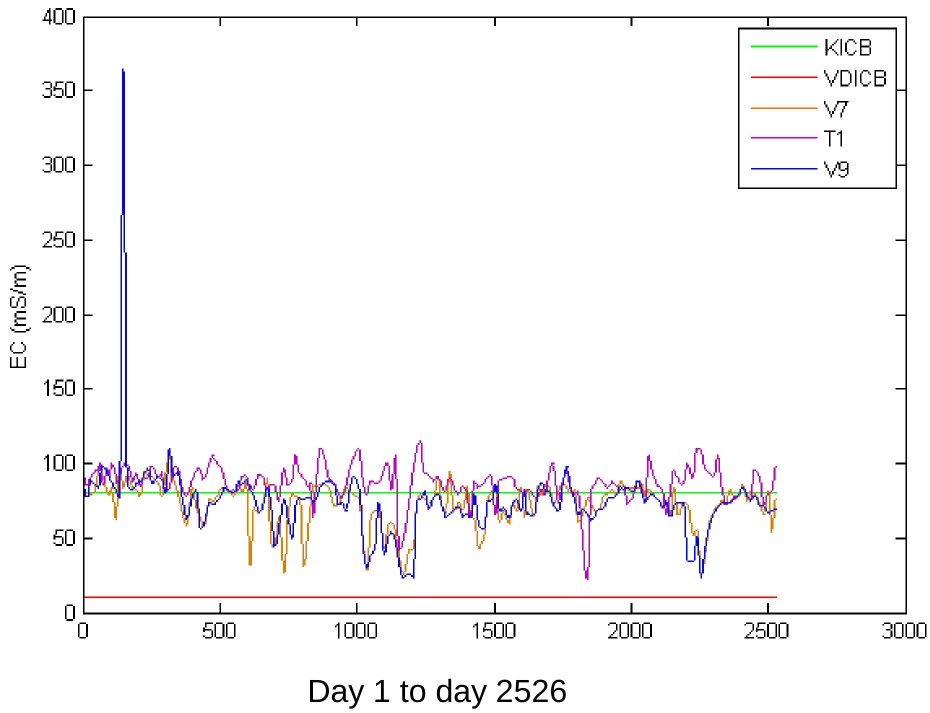



Figure 9: Impact of TR on VR

This could be due to the receptive capacity and the volume of water flowing in the VR. From

Figure 10, it was noted that whatever was happening to the barrage had nothing to do with R1 because its values were well below R2, which was downstream and closer to the confluence RvR/VR.

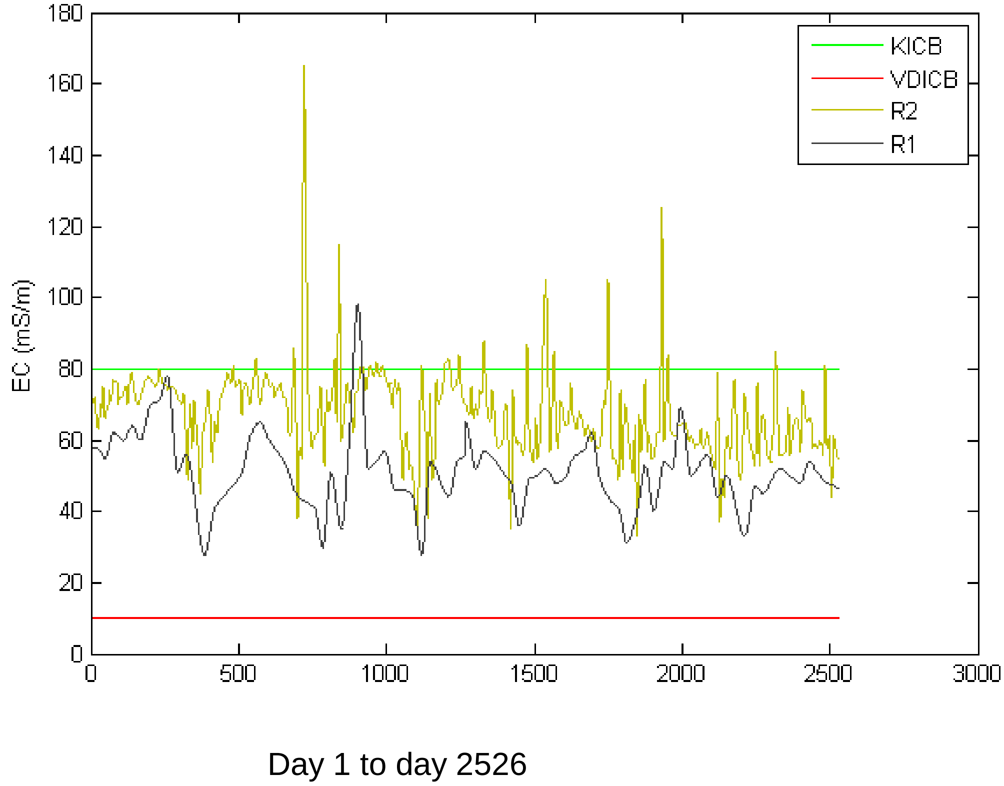



Figure 10: Variation of EC between R1 and R2

Although EC values for R2 were high (

Figure 10), going over the threshold limit in some periods, RvR's impact on VR was very negligible, especially as V7, V9 and V12 values were similar. LR's impact on VR was also negligible, as was that of T1 on VR.

Figure 12 presents the variation of EC along VR, from V2 through to V19 in the MVWMA. It was worth noting that while EC was very low at V2, as soon as SR off-loaded its pollution components into VR through S4, VR did not recover up to V19, which was located well into the MVWMA. There was no significant attenuation of EC values, nor was there significant increase after V7, as noted in comparison against the harmonised guideline values. This presented the fact that SR was the single major contributor of EC impacters on VR. Any mitigatory measures aimed at reducing EC had to be targeted on SR.

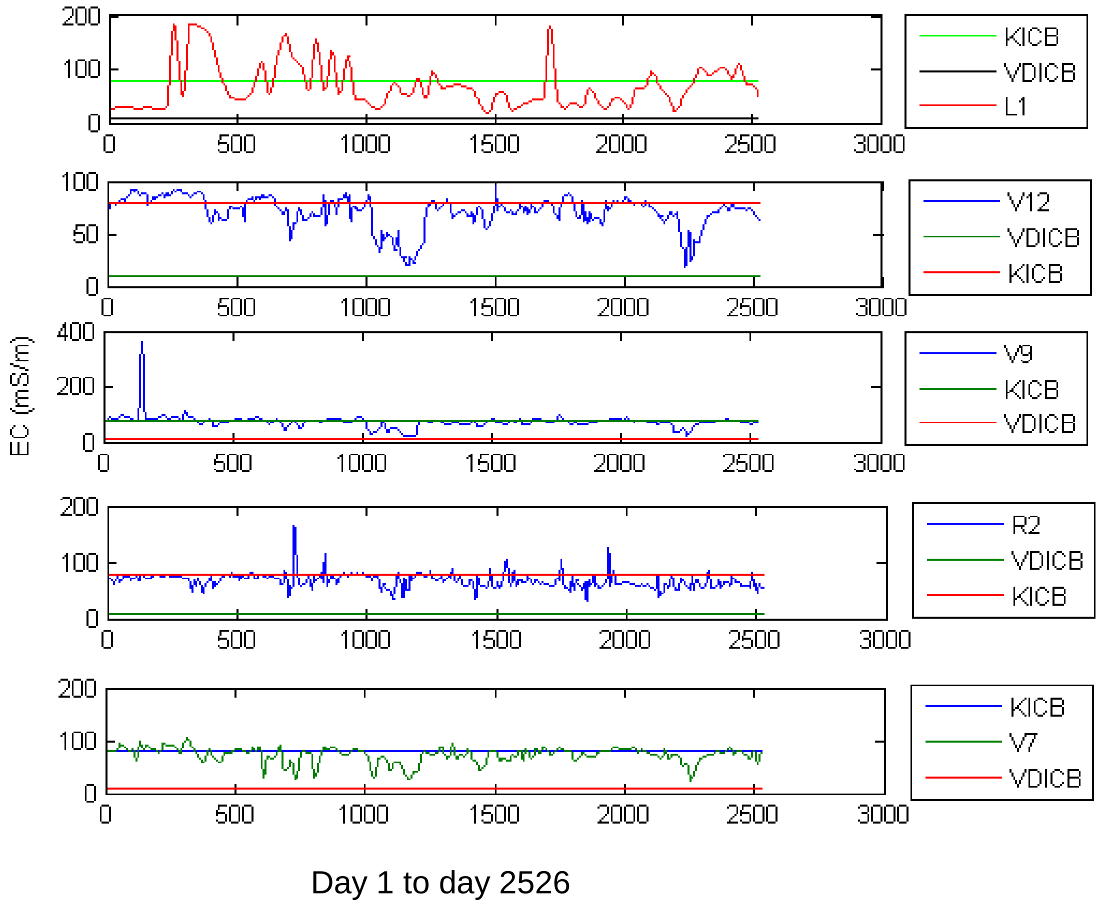



Figure 11: Impact of RvR on VR

V2, V17 and V19 in

Figure 13 represent WBs that treated surface raw water to potable standard. While V2 indicated very low values, close to the VDICB, V17 values were around the KICB while those for V19 were above the guideline limit.

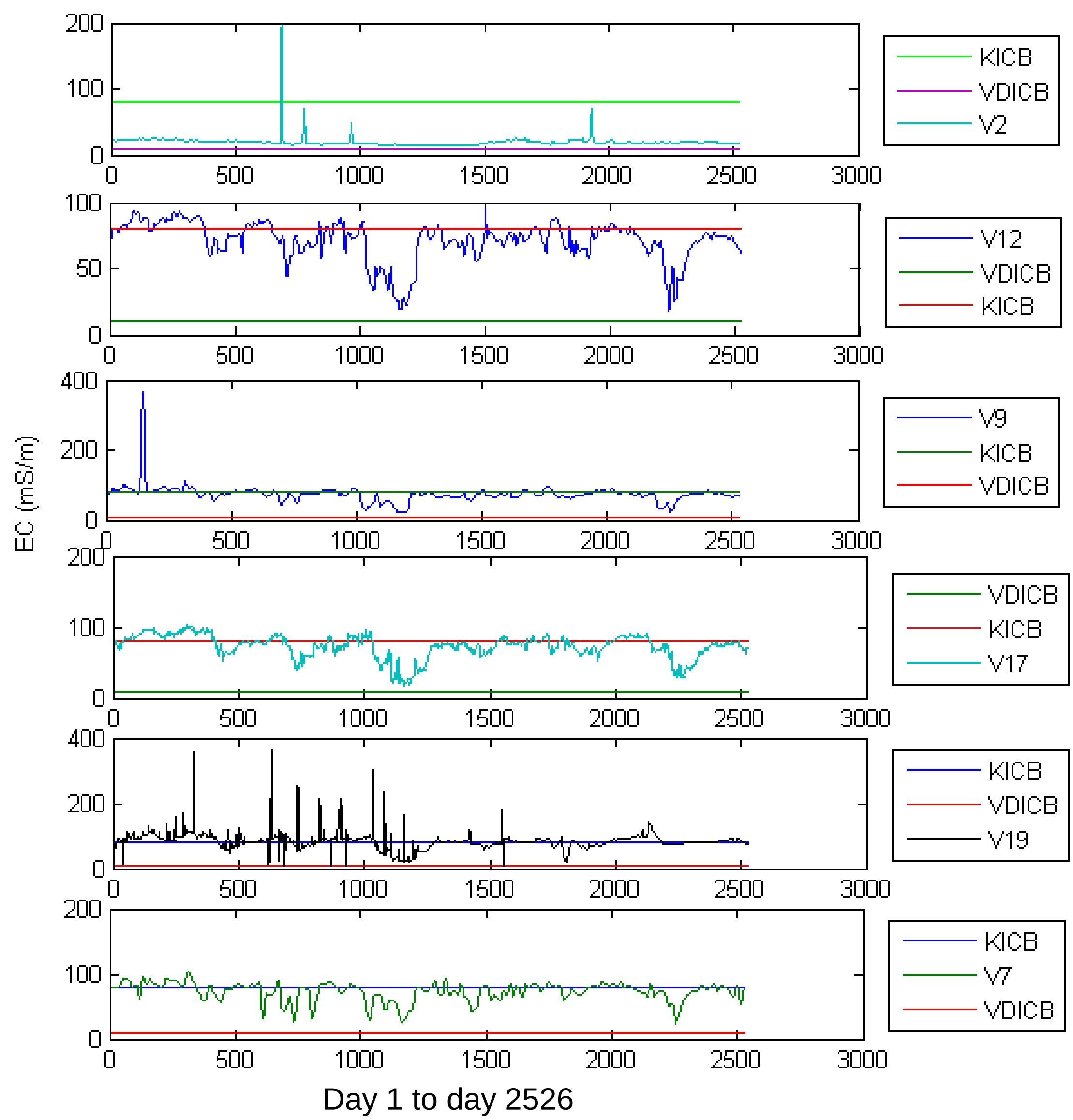



Figure 12: Variation of EC along the VR main channel

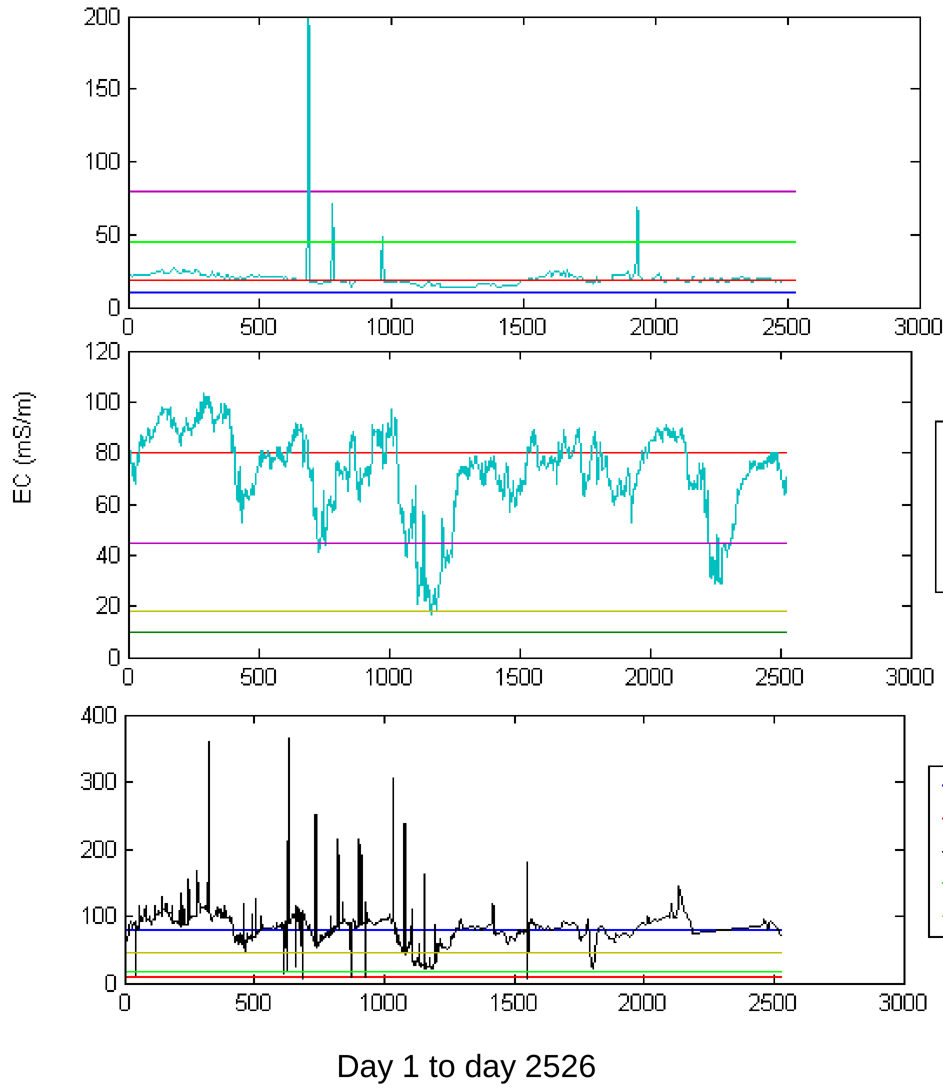



Figure 13: Comparison of EC values among the WBs

**CONCLUSIONS**

V2 water quality fell close to, but above the value for VDICB. This was considered to be good quality water. S4's EC values were above the KICB's 80 mS/m value making that water poorer in quality than that at V2. SR's impact on the VR was noted at V7, whose values were above close to the value for KICB. A dilution effect of water quality at V7 by water from the VD could be attributed to the drop in EC values, from those observed at S4. Impact of K9 was also monitored at V7. K9 values were generally high but KR's impact on VR was overshadowed by SR's impact. Although EC values for TR were higher than for KICB, TR did not have a significant influence on VR at V9.

It was noted that although the tributaries T1, L1 and RvR were polluted, their impact on the VR's water quality was either insignificant or their pollution maintained the high EC values at their points of entry (generally between 80 and 100 mS/m).

Figure 13 compared the quality of raw water abstracted by WBs at V2, V17 and V19, among themselves and against the lower and upper bounds of the harmonised guideline values VDICB and KICB. The WB at V2 treated better quality water for potable use than that we treated V17 and V19 raw water for which EC values fluctauted around 80 – 100 mS/m.

Mitigatory measures to combat pollution and restore the pristine ecological functionality in the VR could be directed towards SR, which heavily impacted VR through S4. Further upstream, the pollution source was through B1 because upstream of confluence BR/SR, SR water was of good quality as noted at S1.

From the key in Table 1, an IEF based on EC, is presented using descriptive implications of pollution loads using colour codes in

Table 2 and spatially in Figure 14.

Table 1: Key for Ecological Functionality

| Colour code | Median EC (mS/m) |
|---|---|
| | 10 - 18 |
| | 19 - 45 |
| | 46 - 80 |
| | 80< |
| | 81 - 100 |

The IEF was based on the 4 categories of the harmonised catchment background values for the VDICB, BSICB, VBIDC and KICB. A special category for values close but above the upper limit of KICB was created to accommodate values between 81 and 100 mS/m. It was felt that it would be unfair to lump these values together with the higher values like 200 mS/m, when in essence they overshot the upper limit by about 3 EC values.

Table 2: Ecological Functionality of U&MVWMAs

| Code | ID | Ecological functionality |
|---|---|---|
| | B1 | highly impacted |
| | K1 | Intermediate impact |
| | K2 | highly impacted |
| | K3 | Intermediate impact |
| | K4 | highly impacted |
| | K6 | Intermediate impact |
| | K10 | Intermediate impact |
| | K12 | highly impacted |
| | S1 | fairly good quality |
| | K9 | Intermediate impact |
| | S4 | highly impacted |
| | V7 | Intermediate impact |
| | V9 | Intermediate impact |
| | L1 | Intermediate impact |
| | R1 | Intermediate impact |
| | R2 | Intermediate impact |
| | T1 | fairly highly impacted |
| | V12 | Intermediate impact |
| | V2 | good quality |
| | V17 | Intermediate impact |
| | V19 | fairly highly impacted |

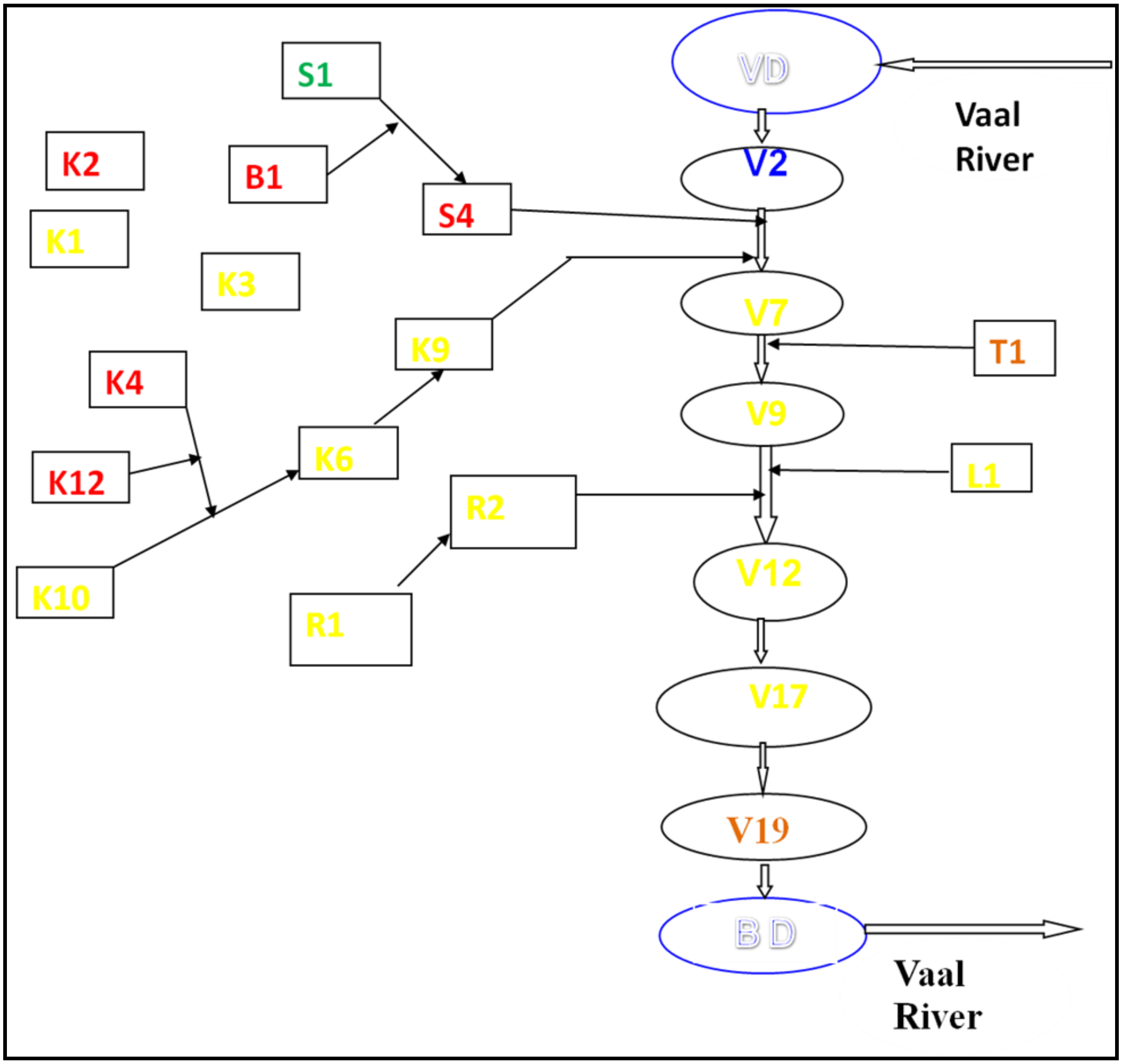



Figure 14: Ecological Functionality of specific reaches of the VR

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