A FEASIBILITY EVALUATION OF THE TOTAL MAXIMUM DAILY (POLLUTANT) LOAD (TMDL) APPROACH FOR MANAGING EUTROPHICATION IN SOUTH AFRICAN DAMS

Report to the
WATER RESEARCH COMMISSION

by

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Roodeplaat Dam (Gauteng, South Africa) on 28 November 2014. With 62% of South Africa's largest dams eutrophic or hypertrophic (Matthews 2014) the need for nutrient attenuation interventions is long overdue. Catchment-based audits of nutrient generation, such as the Total Mean Daily Load (TMDL) protocol provide a means of identifying and prioritizing load reductions.

EXECUTIVE SUMMARY

Total Maximum Daily Loads (TMDLs) are (i) a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and (ii) an allocation of that amount to the pollutant's individual sources. The TMDL protocol was developed in the USA in support of the Clean Water Act of 1972. TMDLs can be applied to any pollutant, *inter alia* bacterial, pathogens, suspended solids, sediments, trace metals and nutrients. The TMDL approach can be applied to both lentic and lotic waters.

TMDLs are intended to be a binding, legal tool to control the discharge of pollutants by source. TMDLs are set at various temporal frequencies that depend both on the nature of the impact they cause, as well as their generation in the watershed. These frequencies range from daily, through weekly, monthly or seasonally, to annually. The setting of the TMDL is linked to a specific threshold or impact response in the receiving waterbody, ideally linked to a biological criterion. The threshold or impact is defined by the loss of beneficial or designated use that the pollutant(s) impart when specified levels are exceeded.

Annual TMDLs for phosphorus loadings to certain South African dams have been provisionally estimated (Harding 2008). The latter work indicated the need for a by-source resolution of the loadings in order to inform, for example, the Waste Discharge:Charge System (WDCS) of the Department of Water Affairs.

TMDLs range from simple calculations to complex, multi-source and type considerations. For TMDLs to be effectively used, they require substantial and relevant data input, as well as well-developed skills and understanding of the cause and effect relationships in the receiving waterbody. TMDLs are waterbody or catchment-specific other than in the crudest of cases – for example where a single wastewater treatment works contributes the entire excess loading. A paucity of data generally results in a need for reliance on models, with resultant loss of confidence with which the TMDL can be set. The use of models is also heavily reliant on limnological skills that can inform the accuracy with which the model predictions are made. These requirements point to a range of TMDL applications, from “rapid” to “comprehensive”, depending on the level and quality of data and skills that are available. The effectiveness of TMDLs is determined by a targeting suite of monitoring that encompasses both biological and water quality criteria.

South Africa currently lacks the data support and reservoir-limnology skills that would be needed to implement a similar TMDL protocol per the format used in the USA. The selfsame limitations constrained the application in the USA until the late 1990s. The setting of TMDLs would be heavily reliant on the use of unsupported modelling of the cause and effect. With respect to South African reservoirs (dams) no program of limnological skills-development exists. As such, application of the TMDL protocols, *per se*, would not be a feasible undertaking until such time a relevant skills base has been developed.

Despite the obvious limitations, the TMDL protocol remains the only rigorous and researched application of its type. This project undertook a feasibility evaluation of the protocol in order to determine (a) those aspects thereof that can be used and supported by existing skills and information and (b) the immediate skills and information needs that require development in order to effectively utilize the protocol or a variant thereof.

This project has sought to determine catchment-derived point and non-point source Total Phosphorus loads, in two case studies, via a combination of methods, viz. runoff and export coefficient based, in-stream determination of loads based on flows and concentration, and the estimation of loads based on the load:response (modelled) characteristics of a target impoundment. The results indicate that the three approaches produce comparable results with low to medium confidence. Contrary to expectations, high non-point source contributions from agriculture were not identified. On the contrary, dry season abstraction of irrigation water from the assessed watercourses suggests that, at least in the Western Cape, agriculture removes a substantial portion of the total load.

This project focussed centrally on the question "Can a TMDL be formulated in South Africa using only existing data and tools?" The approach adopted in this project indicates that the answer is a resounding but qualified "yes" and that the formulation of a Rapid TMDL, disaggregated over a range of temporal scales, is achievable using existing data, dataprocessing tools and information. The approach followed has supported the determination and cross-checking of loads via three pathways. Central to this process is the use of the FLUX32 software, a readily obtainable, easy to use and versatile tool for the conversion of flow and concentration data into parameter loads. The generation of loads, both point and non-point, was characterized as highly seasonal, with as much as 80% of the total annual load generated during the wet season from April to September. Depending on the degree of resolution of the catchment audit, other point- and non-point sources can be added to the loading profile with ease.

For more complex TMDLs, additional hydrological, hydraulic and other information will be needed. The formulation of such TMDLs will likely be more costly as they will require input from, for example, hydrologist engineers. A general limitation in the DWS database is that water quality data are based at best on 14-day intervals. Accordingly, relative long chronological sets of data are required in order for a program such as FLUX32 to accurately infill missing data – especially where the pollutant in question is not strictly correlated with flow. Analysis of several datasets from different systems is required to elucidate the strength of the relationships between flow and concentration.

The need for the development of South Africa-specific runoff coefficients for nutrients should be predicated on the findings of more TMDLs developed using the simple methodology employed in this project. It may well be the case that generic coefficients, already developed for various landuse types in other countries, may suffice. The examination of a larger suite of case studies, in which wastewater effluents play a varying role in the total loading, should indicate the amplitude of non-point source runoff from, for example, areas of urban development.

This project assessed two scenarios, the first in which wastewater (point-source) loading was profoundly dominant, and the second in which background loading was the primary nutrient source but with wastewater effluents already at the limit beyond which the receiving waterbody might be more seriously impacted. In both cases, the simple expedient of imposing the South African 1 mg per litre Special Phosphate Standard would obviate the need for the imposition of a TMDL and provide both relief from extant pollution excesses and time to more closely examine and audit non-point pollution sources.

Rapid TMDLs can be applied to the determination of a variety of problems, ranging from salinity and suspended solids, the maintenance of dissolved oxygen levels and other physico-chemical issues through to impacts of specific toxicants.

While a suite of various TMDL-related models and tools were identified during this project, it was apparent that, without exception, the use of these in a South African context would require further model development, preparation of supportive databases, benchmarking and relatively-wide spatial testing across a variety of catchments in order to dovetail these tools with locally-relevant information. It is anticipated that, should and when the need for higher confidence TMDLs become a reality in South Africa, such supportive instruments would be developed on a catchment-specific basis, for example for sections of the Vaal or Crocodile Rivers. A more immediate and readily achievable goal would be to compare loads at gauged points with the upstream landuse characteristics, for example downstream of mining activities, large urban conurbations as well as for sections of largely undeveloped catchments. In this manner the validity of export coefficients can be determined using already existing data and information in a rapid and semi-automated spatial analysis process.

A word of caution: the value of TMDLs lies in their being set based on known and well-defined problems identified for a particular impoundment, river or wetland. In the absence of a detailed knowledge and understanding of the cause and effect pathway(s) giving rise to the problem, the necessary TMDL rule cannot be formulated. As described in this project, the setting of a desirable Total Phosphorus target level for South African impoundments is based on a previously-generated generality of responses and lacks any intra-impoundment load:response specifics. Not all impoundments will respond in similar fashion to applied nutrient reduction and, unless the case-specific factors are known, nothing more than a Rapid TMDL is indicated. Wastewater-derived nutrient loading levels in South Africa are generally very high and their reduction can only impart improved water quality and a slowing of the process of eutrophication. As noted above, a first point of departure in this process would be the imposition of the Special Standard for phosphate. Minimizing waste generation at source is a central tenet of South Africa's Pollution Control and Waste Management legislation.

Lastly, the term Total Maximum Daily Load (TMDL) is somewhat confusing to many – especially as in most cases it is applied on a seasonal basis and in rare instances at monthly or finer scales of temporal resolution. In simple terms, a TMDL is the maximum amount of a pollutant that a waterbody can assimilate before undesirable physical, chemical and/or biological thresholds are exceeded and the 'fitness for use' of the water resource becomes impaired. It is suggested here that a term that is more easily associated with the approach of pollutant load audit and reduction is used in South Africa. One such option could be 'Pollutant Load Allocation' – wherein 'pollution' is defined as "*the man-made or man-induced alteration of the chemical, physical, biological and/or radiological integrity of water*" (USA Clean Water Act).

Nutrient (pollutant) load budgets can be determined with a low to medium level of confidence using existing data resources. While TMDLs *sensu strictu* are arguably too demanding of data and information and likely to be very costly (a situation that South Africa cannot afford), a derivative thereof, utilized as the basis of a pollutant audit for key catchments and water resources, both lotic and lentic, is clearly indicated. Equally important is the development of reservoir-specific fate of pollutants in terms of uptake, retention and discharge. The formulation of nutrient budgets would provide a logical basis on which to develop a wider understanding of the causes and consequences of, and remedial options for, eutrophication in South Africa.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

Allocations. That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.

Ambient water quality. Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health.

Anthropogenic. Pertains to the influence of human activities.

Antidegradation policies. Policies that are part of each state's water quality standards. These policies are designed to protect water quality and provide a method of assessing activities that might affect the integrity of water bodies.

Aquatic ecosystem. Complex of biotic and abiotic components of natural waters. The aquatic ecosystem is an ecological unit that includes the physical characteristics (such as flow or velocity and depth), the biological community of the water column and benthos, and the chemical characteristics such as dissolved solids, dissolved oxygen, and nutrients. Both living and non-living components of the aquatic ecosystem interact and influence the properties and status of each component.

Assimilative capacity. The amount of contaminant load that can be discharged to a specific water body without exceeding water quality standards or criteria. Assimilative capacity is used to define the ability of a water body to naturally absorb and use a discharged substance without impairing water quality or harming aquatic life.

Background levels. Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.

Bacteria. Single-celled microorganisms. Bacteria of the coliform group are considered the primary indicators of faecal contamination and are often used to assess water quality.

Bacteria source tracking (BST). A collection of scientific methods used to track sources of faecal contamination.

Benthic. Refers to material, especially sediment, at the bottom of an aquatic ecosystem. It can be used to describe the organisms that live on, or in, the bottom of a water body.

Benthic organisms. Organisms living in, or on, bottom substrates in aquatic ecosystems.

Best management practices (BMPs). Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and non-structural controls and operation and maintenance procedures.

Clean Water Act (CWA). The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is section 303(d), which establishes the TMDL program.

Conventional pollutants. As specified under the Clean Water Act, conventional contaminants include suspended solids, coliform bacteria, biochemical oxygen demand, pH, and oil and grease.

Critical condition. The critical condition can be thought of as the "worst case" scenario of environmental conditions in the water body in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g. flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.

Designated uses. Those uses specified in water quality standards for each water body or segment whether or not they are being attained. All Virginia waters are designated for the following uses: recreational uses, e.g. swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g. fish and shellfish.

Discharge. Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.

Dissolved oxygen (DO). The amount of oxygen dissolved in water. This term also refers to a measure of the amount of oxygen available for biochemical activity in a water body, an indicator of the quality of that water.

Drainage basin. A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.

Ecosystem. An interactive system that includes the organisms of a natural community association together with their abiotic physical, chemical, and geochemical environment.

Effluent. Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.

Endpoint. An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).

Existing use. Use actually attained in the water body on or after November 28, 1975, whether or not it is included in the water quality standards (40 CFR 131.3).

Fate of pollutants. Physical, chemical, and biological transformation in the nature and changes of the amount of a pollutant in an environmental system. Transformation processes are pollutant-specific. Because they have comparable kinetics, different formulations for each pollutant are not required.

Faecal Coliform. Indicator organisms (organisms indicating presence of pathogens) associated with the digestive tract.

Geometric mean. A measure of the central tendency of a data set that minimizes the effects of extreme values.

Geographic Information System (GIS). A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth.

Hydrologic cycle. The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.

Hydrology. The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Indicator. A measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality.

Indicator organism. An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.

Load allocation (LA). The portion of a receiving waters loading capacity attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished (40 CFR 130.2(g)).

Loading, Load, Loading rate. The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.

Loading capacity (LC). The greatest amount of loading a water body or watershed can receive without violating water quality standards.

Margin of safety (MOS). A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving water body (CWA section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).

Mathematical model. A system of mathematical expressions that describe the spatial and temporal distribution of water quality constituents resulting from fluid transport and the one or more individual processes and interactions within some prototype aquatic ecosystem.

Mean. The sum of the values in a data set divided by the number of values in the data set.

Mg/l. Milligram per litre.

Monitoring. Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.

Narrative criteria. Non-quantitative guidelines that describe a desired water quality goal or goals.

Natural waters. Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.

Nonpoint source. Pollution that originates from diffuse sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

Numeric targets. A measurable value determined for the pollutant of concern, which, if achieved, is expected to result in the attainment of water quality standards in the listed water body.

Point source. Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollutant. Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA section 502(6)).

Pollution. Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

Per the SA National Water Act, ‘pollution’ is the direct or indirect alteration of the physical, chemical or biological properties of a water resource so as to make it less fit for any beneficial purpose for which it may be reasonably expected to be used; or harmful to the welfare, health or safety of human beings, to any aquatic or non-aquatic organisms; to the resource quality or to property.

Public comment period. The time allowed for the public to express its views and concerns regarding action by EPA or states (e.g. a *Federal Register* notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).

Receiving waters. Creeks, streams, rivers, lakes, estuaries, ground-water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.

Residence time. Length of time that a pollutant remains within a section of a stream or river. The residence time is determined by the streamflow and the volume of the river reach or the average stream velocity and the length of the river reach.

Septic system. An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a drain field or subsurface absorption system consisting of a series of percolation lines for the disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.

Sewer. A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.

Stakeholder. Any person with a vested interest in the TMDL development.

Standard. In reference to water quality (e.g. 200 cfu/100 ml geometric mean limit). See the definition for Water quality standard.

Streamflow. Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" since streamflow may be applied to discharge whether or not it is affected by diversion or regulation.

Substrate. Bottom sediment material in a natural water system.

Surface runoff. Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.

Surface water. All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.

Technology-based standards. Effluent limitations applicable to direct and indirect sources that are developed on a category-by-category basis using statutory factors, not including water quality effects.

Total Maximum Daily Load (TMDL). The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Transport of pollutants (in water). Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water.

Tributary. A lower order-stream compared to a receiving water body. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.

Waste. Any substance, whether or not that substance can be reduced, re-used, recycled and recovered –

a. that is surplus, unwanted, rejected, discarded, abandoned or disposed of;
b. which the generator has no further use of for the purposes of production;
c. that must be treated or disposed of, or
d. that is identified as a waste by the Minister by notice in the Gazette, and includes waste generated by the mining, medical or other sector, but –
e. by-product is not considered waste; and
f. any portion of waste, once re-used, recycled and recovered, ceases to be waste.

(per SA National Environmental Management Act 59 0f 2008).

Wasteload allocation (WLA). The portion of a receiving waters' loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).

Wastewater treatment. Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants.

Water quality. The biological, chemical, and physical conditions of a waterbody. It is a measure of a water body's ability to support beneficial uses.

Water quality criteria. Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.

Water quality standard. Law or regulation that consists of the beneficial designated use or uses of a water body, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular water body, and an antidegradation statement.

Watershed. A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

µg/l. Microgram per litre.

1 LITERATURE REVIEW

The excessive fertilization (eutrophication) of freshwater, estuarine and marine resources is a long-standing and well-understood threat to the socio-economic development of any nation. In cases where urban runoff or wastewater effluent disposal occur, eutrophication may be accompanied by pollution from faecal bacteria and/or chemicals or pharmaceuticals associated with human waste. Despite this, relatively little action has been taken to address and attenuate the discharge of inadequately-treated wastewater effluents into surface water resources. As a result, the problem is now at a stage where remedial interventions will be of long-duration and extremely costly. Additionally, the need to address the problem and why needs to form the basis of public-education and information programs as, in many cases, funds necessary for mitigation will need to be sourced from rates and taxes. Had the problem been acknowledged many years ago and ‘phased-in’, it would have now become part of the social consciousness. In South Africa, the sustained inaction to the threat that eutrophication poses to future development remains to be addressed at any meaningful level.

1.1 TMDLs and eutrophication

For four decades the United States, per the Clean Water Act (CWA), has been developing nutrient criteria for impaired water bodies. The Total Maximum Daily Load (TMDL) approach has formed part of the United States Clean Water Act since promulgation of the latter in 1972. The TMDL approach, while sound in theory, has proved difficult to implement and has and is subject to controversy and criticism (e.g. FTN 2002). Despite this, it remains the only reasonable framework in existence for objectively managing eutrophication on and equitable basis.

Although initiated in the 1970s, a surge in TMDLs in the USA only occurred from the mid-1990s onwards. The reasons for this devolved to the technical, data and other issues required for the process (e.g. Bosch 2003). The reasons for the apparent shortcomings of the TMDL approach form the focal point of departure for this project. It is not the intention of this project to replicate the TMDL protocol as advocated in the USA; rather it is the intention to seek a derivative of the approach that will be suitable for South African use as a support tool for the Waste Discharge: Charge System (WDCS). Accordingly, the intention is to highlight the principle strengths and weaknesses of the TMDL approach, take advantage of the strengths and endeavour to avoid or ameliorate the weaknesses. As such, this overview concerns itself with these issues and not the history of TMDL development *per se*. For a review of the latter the reader is referred to USEPA (2001).

<u>This project</u> focuses only on the methodological approach for disaggregating pollutant loads and does not concern itself with the not-insubstantial policy and legislative issues that link the approach to the CWA (CWA Sections 305[b] and 303[d]); In this regard it should also be noted that while the US Environmental Protection Agency (USEPA) prohibits, via the National Pollution Discharge Elimination System (NPDES), the discharge of various pollutants and toxic compounds, the regulation thereof devolves to the individual states. In broad terms the NPDES finds equivalence with the South African WDCS. Additionally, this project does not consider the importance of stakeholder buy-in and involvement.

TMDL (Definition, USEPA) *A TMDL or Total Maximum Daily Load is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources*.

A TMDL is a detailed (by source and quantity) mass-balance model for a particular pollutant flowing into and out of a watershed. The approach is used to determine the maximum assimilable amount of pollutant 'x' that a particular watercourse or waterbody can receive, without failing to meet set desirable or 'beneficial use' targets. The aggregate load is then apportioned over all identified sources and further disaggregated, where possible, on a temporal scale that takes into account seasonal or other variations in both flow and loading. The concept of "daily" load is notional, most TMDLs are compiled at longer timescales, ranging between weekly to monthly (most common) to annual. While in some cases an annual load may suffice, it is often the case that the aggregate load varies considerably with respect to runoff characteristics, i.e. more accurately quantified – and hence managed – over a shorter temporal scale.

In summary a TMDL comprises six elements:

1. **Problem definition** (a description of the location and scope of the project area, and the waterbodies and pollutants being addressed);

2. **Endpoint identification** (a specification of the desired condition, linked to a specific water quality standard);
3. **Source analysis** (a list of the types, magnitudes and locations of all sources contributing to the impaired condition);
4. **Linkages between sources and receiving water** (details of the relationship between cause and effect, most often generated by use of models);
5. **Margin of safety** (allowance for uncertainty in the modelling predictions or data);
6. **Loading allocations** (allocation of the desired total pollutant loading across all sources)

A great number of TMDLs have been completed to-date, covering a range of issues from meeting dissolved oxygen targets, to trace metals, nutrients, sediments and salts. As of 2001, the estimate for the USA was for the completion of 40 000 TMDLs by 2015 (Whittemore and Ice, 2001). The best review of the overall US-TMDL program is found in the summary of a USEPA inter-disciplinary workshop on the topic (USEPA 2011). As of 2012, the USEPA reports via its website that 45 000 TMDLs have been completed (see link following):

http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/results_index.cfm

Bosch (2003) reported that the cost of the US-TMDL program is overwhelming. The USEPA issued a draft report on the 2000 TMDL program, estimating average annual costs to states and the EPA of developing TMDLs could be $63 to $69 million, while implementation costs could be between $900 million and $4.3 billion per year (here it should be noted that these figures are a decade old). Most states lack the personnel and the financial resources to carry out the TMDL program as intended. In particular, little has been done to ensure that the implementation plans will be carried out. Furthermore, the states are prevented from monitoring for a full suite of indicators to assess the condition of their waters and from adequately implementing land use changes.

A typical TMDL submission would contain the following elements:

- Identification of Waterbody, Pollutant of Concern, Pollutant Sources, and Priority Ranking;
- Applicable WQS & Numeric Water Quality Target;

- Loading Capacity;
- Load Allocations and Waste Load Allocations;
- Margin of Safety;
- Consideration of Seasonal Variation;
- Reasonable Assurance for PS/NPS;
- Monitoring Plan to Track TMDL Effectiveness;
- Implementation Plan;
- Public Participation

The foregoing notwithstanding, the TMDL process provides a workable and researched skeleton upon which a variant of the original intention may be forged and which will meld with local (South African) needs. If reservoirs are to be protected then the sources of the pollutant problem(s) in each case need to be defined and attenuated.

1.2 THE SOUTH AFRICAN SITUATION

A considerable percentage of South Africa's watercourses and waterbodies are impaired by various forms of pollution (Driver et al. 2011; Nel and Driver 2011). Many sections of South African rivers act as conveyances for wastewater effluents of various qualities and, in the landlocked provinces, wastewater effluents can comprise a substantial portion of the annual water balance for water storage reservoirs. Many reservoirs are enriched with nutrients and have been so for several decades. Many more reservoirs are on a trajectory of change towards an elevated and potentially-problematical trophic state. It is this group of reservoirs that will benefit most from proactive TMDL-based protection and management.

Antecedent to this study, two bodies of work have provided tools and information regarding the nature and extent of the South African eutrophication problem, in particular the impact associated with excessive loading of phosphorus into lentic environments. The first of these efforts was the development of the Nutrient Enrichment Assessment Protocol (NEAP), developed as part of a watershed-level guide for eutrophication assessments (Rossouw et al. 2008). The NEAP model provides a simple means of both forward and reverse-modelling nutrient loads in order to determine the in-lake concentration of phosphorus. The criterion for beneficial use utilized the frequency of algal blooms, measured as chlorophyll-a. The model is a simple, annual time-step, flushing-corrected tool with the ability to quantify non-point source loads based on landuse and export coefficients. The selection of model algorithms is based on a best-fit analysis for a group of similarly-impacted, short retention time, reservoirs. The NEAP assessment included the establishment of a generic target value for Total Phosphorus (TP) of 55 µg ℓ^{-1} in-lake (Rossouw et al. *ibid*).

The intention to upgrade and further develop NEAP to a multi-model toolkit has not yet been approved for funding.

The second study entailed the determination of the annual maximum phosphorus loads, designated 'TMAPLS' for a set of impaired South African reservoirs (Harding, 2008). The target level was the threshold for mesotrophy in each reservoir (= the aforementioned value for TP). This assessment revealed that the most impaired reservoirs are typically impacted by wastewater effluents, i.e. by point source loadings. A second group have a substantial loading derived from urban non-point sources, whereas the third group were dams that are small in relation to the size of their catchment and where the background loading alone exceeds the thresholds for the TP-related trophic condition.

Both the aforementioned studies indicated the need for a higher level of resolution in defining the loading characteristics in order to accommodate seasonal variations in hydrology, algal growth season and allowance for water level (reservoir volume) fluctuations during either intra-annual drawdown or drought periods.

In addition to the foregoing, an independent study that assessed the levels of chlorophyll in South African dams, using satellite imagery, found that 62% of the largest dams to be eutrophic or hypertrophic (Matthews 2014). This number accords with an examination of in-reservoir total phosphorus concentrations determined from DWS data (Harding, submitted). As such, the combined findings reveal a dire and very serious level of raw potable water quality impairment, and with wastewater effluents contributing substantially to the situation.

There is a fundamental difference between the water resource pollution situation in the USA and that in South Africa. In the USA, a not-inconsiderable amount of effort has been devoted to addressing pollution from wastewater treatment plants (WWTWs), to the extent that some WWTWs can now achieve exceedingly low Total

Phosphorus final effluent concentrations of 0.1 mg ℓ^{-1} (e.g. USEPA, 2007) – this being at least an order of magnitude or more than the levels typically achieved in South Africa – where effluent P concentrations commonly exceed 5 mg ℓ^{-1}. There is now a general acceptance in the USA that point sources of pollution have been successfully addressed and the extant focus is now on non-point sources.

The point must be made that the generation of wastewater effluents is an inevitable side-effect of life and, as such, cannot be eliminated as a source of pollution. If, however, the waste is handled and disposed of in an acceptable fashion, taking into account the impacts thereof on the waterbodies to which it is disposed, it need not cause pollution.

1.3 THE TMDL PROTOCOL

The TMDL program is required to meet the following goals (USEPA, 2001):

- The TMDL program (see **Figures 1-1 and 1-2**) should focus on improving the condition of waterbodies as measured by attainment of designated uses (see **Note 1**);
- The program should encompass all stressors, both pollutants and pollution (see **Box 1**), that determine the condition of the waterbody;
- Scientific uncertainty is a reality within all water quality programs, including the TMDL program, that cannot be eliminated entirely.

<u>Note 1:</u> The concept of “designated use”:
The ‘designated use’ defines the goal of the water quality standard/guideline. For example, per USEPA (2001), ‘ a designated use of human contact recreation should protect humans from exposure to microbial pathogens while swimming, wading or boating’, and/or ‘harmful substances in water, fish or shellfish’.

In effect the first step in the process requires the identification of the most appropriate indicator of floral or faunal imbalance in a specific lake or reservoir (Havens and Walker 2002).

Designated uses are usually defined in narrative terms but the more descriptive they can be, the better (see **Table 1-1**). Protocols for developing TMDLs for nutrients, sediments and a range of other pollutants have been developed by the USEPA (e.g. USEPA 1999a,b).

The formulation of TMDLs adopts the following general formula:

$$TMDL = WLA + LA + MOS + BG$$

Where

- WLA = wasteload allocation from defined point sources;
- LA = load allocation from non-point sources;
- MOS = margin of safety to ensure attainment of water quality standards;
- BG = background loading

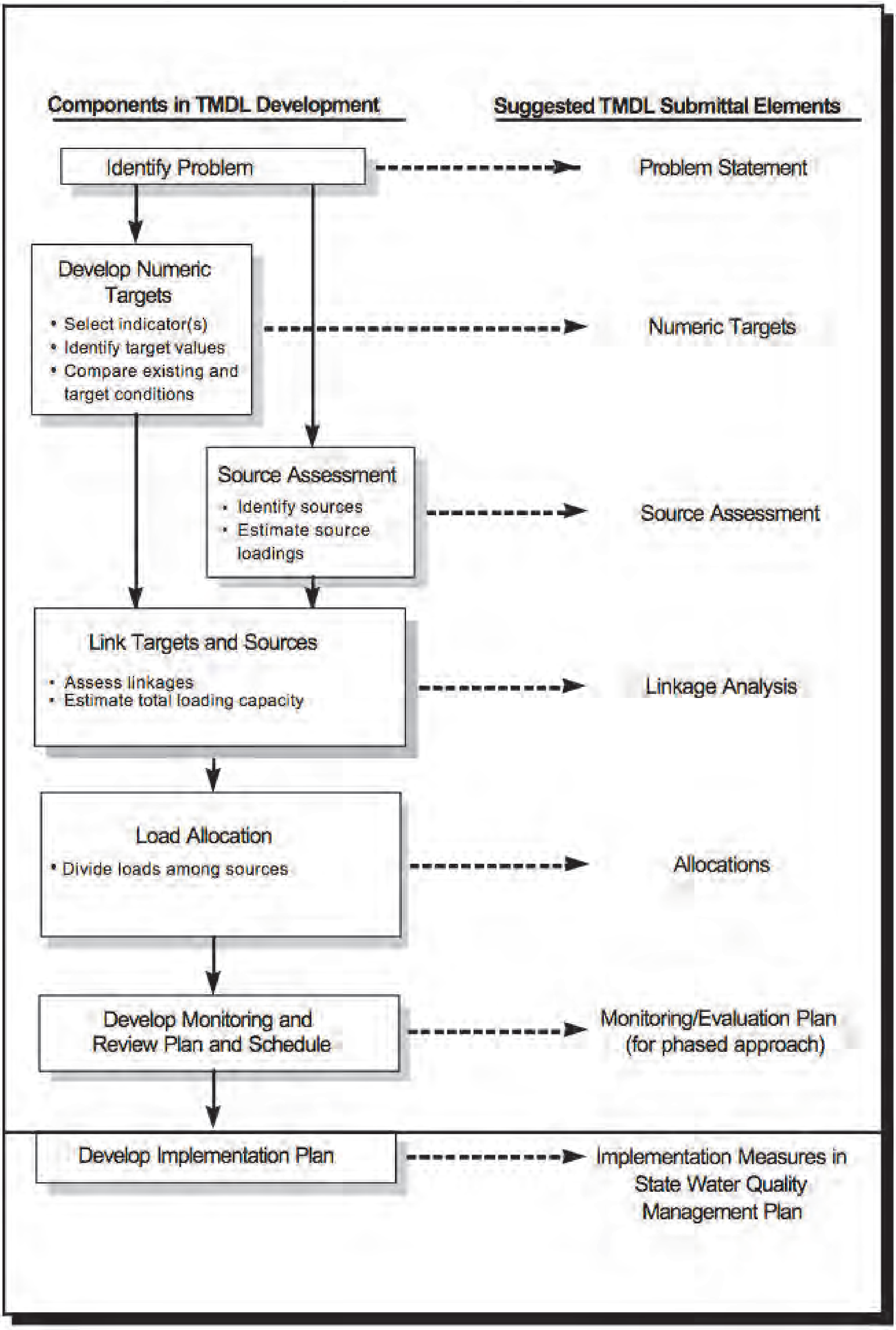

Figure 1-1: Components of TMDL development

(from USEPA 1999a)

Table 1-1: Examples of impacts of nutrients on designated uses (from USEPA 2001)

Designated Use	Problems Associated with Plant Growth Stimulated by Nutrient Loading
Aquatic Life Support	• Low dissolved oxygen concentrations caused by nighttime respiration of large populations of aquatic plants and algae or by the decay of plant matter • Fish kills (via toxicity, or low dissolved oxygen) • Reduced light penetration • Nuisance plants outcompeting desired species
Drinking Water Supply	• Blockage of intake screens and filters • Taste and odor problems • Production of toxins (by blue-green algae) • Disruption of flocculation and chlorination processes in water treatment plants • High nitrates in drinking water, which can cause methemoglobinemia (reduced ability of the blood to carry oxygen), especially in infants
Recreation/Aesthetics	• Reduced clarity by sloughed material • Macrophyte interference with boating, swimming, water skiing, and other recreation • Sloughed material fouling anglers' nets • Floating mats • Slippery beds that make wading dangerous
Industrial	• Blockage of intake screens and filters
Agricultural	• Clogged stream channels, reducing drainage by raising water level and increasing risk of flooding adjacent land

Box 1: Pollution vs Pollutant (from USEPA, 2001)

The term “pollutant” means dredged spoil, incinerator residue, biological materials, radioactive materials, heat, discarded equipment, rock, salt and industrial, municipal and agricultural waste discharged into water.

The term “pollution” means the manmade or man-induced alteration of chemical, physical biological and radiological integrity of water.

Per the USA CWA, pollution includes pollutants (as above), as well as other stressors such as habitat destruction, hydrologic modification, etc.

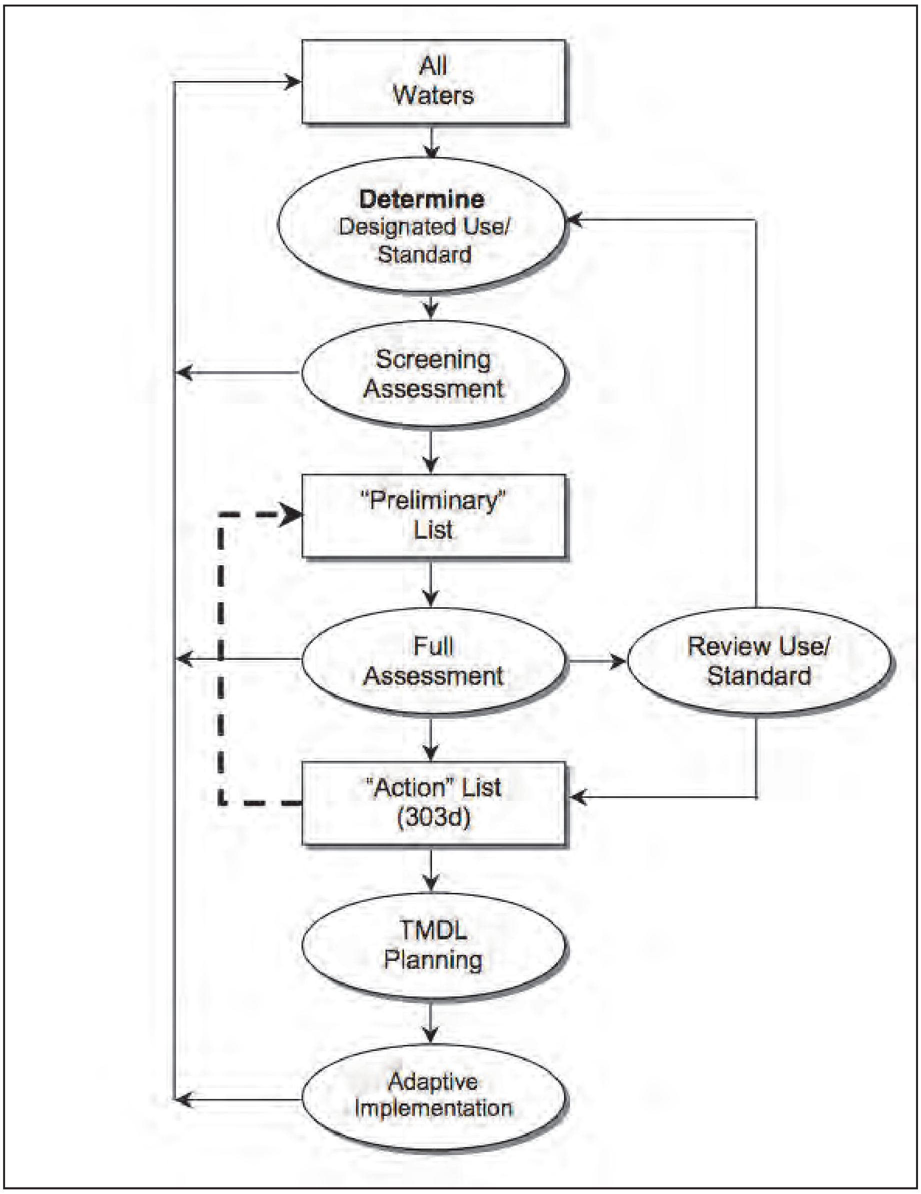

Figure 1-2: Positioning of the TMDL process in relation to the US CWA

1.4 TMDLS ISSUES: THE CONCERNS

Introduction

The TMDL concept, application and practice is probably the most debated environmental regulatory practice in the USA. The approach, while sound in theory, did not or could not identify the mix of constraints that would preclude its easy roll-out as was originally intended. While some TMDLs are relatively easy to compile, others have become major challenges, some costing more than US$1 million. This (high cost) is not a scenario that South Africa can contemplate or afford. South Africa has already experienced, and continues to experience, the cost and skills issues associated with giving effect to the needs of, for example, the Ecological Reserve. As with ecological reserve determinations, TMDLs require the involvement of a wide range of disciplines (ecology, biology, chemistry, hydrology, atmospheric science, meteorology, mathematics, statistics and social sciences) – the consequences of which are high costs. In the absence of a well-developed skills base within the regulating organization, the use of Third Parties to undertake TMDLs inflates the overall costs (see hereunder).

The TMDL concept transformed water resource protection from a 'source by source' approach to one driven by ecological health and function, i.e. the latter dictates the control of pollution emanating from the former (Saltman 2001). This approach brought into play the important consideration of which sources need to be controlled and to what extent. Although sound in concept, TMDLs have not been without challenges and lawsuits have been and are common (Saltman 2001), this despite the fact that TMDLs are required to be developed in consultation with stakeholders (Kishida and Foster 2011).

The formulation of a TMDL encompasses various phases, starting with the listing of the affected waterbody as impaired, the formulation of the TMDL and the compiling of the TMDL "rule" that provides the legal implications thereof. This project is concerned only with the formulation of the TMDL itself and does not address any of the associated policy or drafting issues. An example of a nutrient-based protocol and rule is provided in **Appendix A**.

Point vs non-point sources

The issues surrounding inclusion of point and non-point (NPS) sources of pollution in TMDLs are, in many cases, specific to US and US-Federal legislative instruments and are not relevant to this overview. At the time the CWA/TMDL process was initiated, however, point sources predominated as the major sources of pollution. The USA considers that point source issues have now been addressed and that NPS is now the target focus. In South Africa, however, management of point sources remains the key focus in inland areas, i.e. where disposal of effluents to the marine environment is not practiced. Disposal of inadequately processed wastewater effluents is the major cause of watercourse and impoundment pollution. Allied to this is the fact that wastewater treatment in South Africa, with respect to attenuation of nutrient loads, is not yet aligned in any form or fashion with environmental protection against eutrophication.

There is a train of argument in the USA that maintains that the TMDL process should not engage NPS pollutants. This is founded on a perception that the establishment of NPS TMDLs is difficult and technically challenging. This argument has no basis in fact and the TMDL approach was always intended to incorporate NPS pollution (e.g. Smith 2002).

Atmospheric deposition

The need to include the loadings from atmospheric deposition into TMDLs has presented a range of challenges, not least monitoring and data dependent. The consideration of atmospheric deposition has direct relevance in, for example, TMDLs for sulphate or nitrogen.

Information and data shortcomings

The TMDL approach rests on three pillars of decision-making, all of which are dependent on the availability or collection of appropriate datasets. Firstly, in order to determine the condition of the waterbody and to set its rules for designated use, data need to be available to accurately facilitate this process and to link the effect (in-lake) to the cause (watershed elements). Secondly, watershed-level data and models are needed to establish the aggregate and sub-aggregate loadings to support the allocation of permissible loads by source. Thirdly, long-term monitoring programs, specific to each and every TMDL, need to be established to determine compliance.

Monitoring *per se* is an essential need that is under threat. Efforts to reduce monitoring protocols to the lowest common denominators are globally-common, cost being a common argument. Such arguments, i.e. supporting the motivation for reduced monitoring activities, are arguably short-sighted as they neglect to consider the long-term risks and future costs of doing so.

Reductions in physico-chemical monitoring may, however, be offset against increased use of biological criteria, provided that a substantiated linkage (transfer function) between the water quality and bioindicator are established (e.g. Tibby 2004). It has been demonstrated, for example, that the use of diatoms provides a more accurate indication of bioavailable phosphorus than do repeated measurements of water quality (Stevenson et al. 2010) – this finding highlighting the value of bioindicators to determine the onset of eutrophication in oligo- and mesotrophic reservoirs. In this project assessment, use of the EPA guidelines for identifying appropriate biological indicators will serve as a basis (USEPA 2000).

Reservoir characteristics and application issues

As will be apparent from this analysis, the application of TMDLs to lakes or reservoirs is not a “one size fits all” generic approach. Lakes and, particularly, reservoirs experience considerable ranges of hydromorphological variation, as well as within-basin and sub-basin variations – the latter a function of lake morphology, wind effects (mixing) and lake shore dendricity. As a consequence, the linking of a TMDL for a particular parameter must be based on the specific nature and timing of the in-lake response. In the case of ammonia TMDLs, for example, Gelda and Effler (2003) have demonstrated that the following issues have a fundamental bearing on the validity of the approach:

- Anticipated hypolimnetic oxygenation (aeration) treatment;
- Previously documented in-lake nitrification events;
- Effects of residual industrial pollution on pH;
- Effects of uncertainties and potential bias in in-lake pH measurements;
- Anticipated increases in population growth;
- Changes in the specification of national toxicity guidance criteria.

Gelda and Effler (2003) also identified the following potential pitfalls:

- Arbitrary specification of critical conditions;
- Inadequate specification of the number of exceedance events and their allowable duration;
- Incorrect identification of the month for which the critical concentration is relevant (i.e. assimilative capacity for the lake incorrectly assessed at a temporal scale);
- Lack of recognition of artificial assimilative capacity as a result of anthropogenic influences;
- Setting of too low a ‘margin of safety’;
- Failure to incorporate anticipated increases in loading from, for example, metropolitan sources;
- Basing the modelling and setting of hydrological characteristics on an unrepresentative year or period.

The foregoing represents an astute assessment of the pitfalls that may influence the validity of a TMDL. Importantly, they indicate the importance of any TMDL being based on a thorough understanding of the relevant chemistry and the range of inter-related abiotic and biotic factors that may influence the outcome. Sober reflection on the identified issues provides some substantiation for the high costs of comprehensive TMDLs.

Authors comment: If a TMDL for a parameter with a complicated chemistry (such as nitrogen) is to be appropriately considered, then it is likely that a comprehensive TMDL analysis will be both time-consuming and expensive. This brings into play arguments similar to those experienced in South Africa around the concept of the Ecological Reserve and the establishment of three levels of Reserve (and hence cost implications) viz: the Rapid, Intermediate and Comprehensive Reserves. A similar approach may be feasible for TMDLs but may well constrain enforceability as the directive becomes increasingly arbitrary. It may, however, provide a means of introducing a TMDL over a specified period, the culmination of which would be progress to the next TMDL level. Here the approach suggested by Lee and Jones-Lee (undated) has relevance:

1. Developing a problem statement of the excessive fertilization situation of concern.
2. Establishing the goal of nutrient control (i.e. the desired eutrophication-related water quality).
3. Determining nutrient sources, focusing on available forms.
4. Establishing linkage between nutrient loads and eutrophication response (modelling).
5. Initiating a Phase I nutrient control implementation plan to control the nutrients to the level needed to achieve the desired water quality (= “Rapid TMDL).
6. Monitoring the waterbody for three to five years after nutrient control is implemented to determine whether the desired water quality is being achieved.
7. If not, initiating a Phase II where, through the monitoring results, the load-response model is improved and thereby able to more reliably predict the nutrient loads that are appropriate for the desired water quality (= Intermediate TMDL).

Scale of the problem

Eutrophication becomes prevalent at very low levels of nutrient availability in excess of background concentrations. In the case of eutrophic waterbodies, neither nitrogen nor phosphorus are anywhere close to limiting plant growth (2-8 µg ℓ^{-1} as bioavailable P) and 15-30 µg ℓ^{-1} as N (nitrate and ammonia) (Lee and Jones-Lee, undated; Stevenson et al. 2010).

In the case of eutrophic South African reservoirs, ambient P concentrations are between one and two orders of magnitude higher and with a high level of temporal constancy. As a result, the load reductions required to bring these reservoirs to a likely acceptable level of P enrichment are nothing less than massive (see Harding 2008).

It is also of some importance to note that nutrient availability in excess of background is, in many cases, beneficial. For example, fisheries cannot be sustained on background nutrient levels in oligotrophic lakes. Accordingly, beneficial use considerations must be balanced with ecological needs.

Modelling

One of the consequences of data paucity is an increased reliance on modelling. For models to be accurate, however, they need to be based on and calibrated with comprehensive and relevant data. If not then models (such as data infilling tools) are used to inform load-effect models, with obvious limitations as the uncertainty levels are compounded. Additionally, TMDLs are far from generic as all lakes, for example, do not have the same load:response characteristics. This severely constrains the use of generic models beyond a certain level of confidence and predictive ability. Low-level modelling is not likely to withstand legal challenges and the enforceability of rules based thereon is brought into question.

Critically, the ‘elephant in the room’ here is that in the absence of a developed and long-standing program of the limnological assessment and understanding of reservoirs in a particular region, there may simply be too low a level of load:response understanding to support an enforceable TMDL. As such, the long-standing and seemingly-inexplicable reluctance of the Department of Water Affairs to develop a skills-base for reservoir management may prove to be, singly, the most-important aspect that will confound the application of any “TMDL-type” approach in South Africa.

In a critique of a particular phosphorus TMDL, Effer et al. (2002) highlighted the following shortcomings – aspects that confirm the validity of the preceding statement on the need for a developed national level of understanding of local reservoir limnology – that are likely to be relevant to many TMDL derivatives:

- Failure to identify a P load from the river back into the lake;

- Seasonal plunging of tributaries to depths below the lake's productive level (highlights the need for the use of a mixing model or knowledge of the intra-annual hydrodynamic characteristics of the particular lake or reservoir);
- Aspects of the bioavailability of particulate phosphorus (PP) in the various inputs contributing to the total load;
- False high estimates of TP resulting from turbidity;
- Implications of high lake-flushing rates.

James et al. (2002) pointed out a set of in-lake complications that may confound the setting of a TMDL in certain lakes. These were:

- High and inter-annually variable internal loading;
- Variations in loading resulting from the *en masse* collapse of stands of pondweed;
- Re-suspension of nutrients from sediments disturbed by the action of powerboats.

The aforementioned findings emphasize the need for a rigorous and on-going program of lake assessment in order to ensure that the lake response is correctly linked to the identified loadings.

Assuming that nationally-based criteria and guidelines for nutrients or toxicants exist, their modification to ensure relevance for a specific lake is likely to be extremely costly, especially in cases not supported by appropriate, long-term datasets (e.g. Lee, 2001). This is likely to be the case in South Africa.

In summary, the any applied model should not be more complex than (a) the data allow (de Pinto et al, undated) and (b) where the model output can be verified against empirically-determined load:response characteristics.

Lack of regional datasets and standards

Regionally-relevant data are an extremely important component of water resource management. If not available, management guidance devolves to relatively-crude and generic associations of nutrient loads with, for example, a particular trophic condition, e.g. mesotrophy. While certainly beneficial for some waters, this approach can result in the degradation of others by allowing them to worsen from, for example, oligotrophy to mesotrophy. Regionally-based syntheses, such as those informing the Wisconsin Administrative Code (e.g. Robertson et al. 2001 and 2008) form vital components of any water resource management program. This level of system analysis is currently lacking in South Africa, being partially existent for rivers and completely lacking for reservoirs.

The inappropriate selection or availability of standards for specific waterbodies has been a specific bone of contention in the USA for many years (e.g. Freedman et al, undated). Many waterbodies are already so fundamentally altered that cannot be reversed, i.e. a less-impacted version of the extant condition will need to be the choice (akin to the South African Achievable Ecological Management Class, AEMC, used in river assessments).

Changing conditions

TMDLs have to be entirely adaptive, i.e. they need to continually take into account changing landuse and hence pollution practices and update the TMDL accordingly. While this is part of the aforementioned monitoring activity, it embodies a component of development and landuse planning as well. Once a TMDL is set and ANY component of the extant loading or ANY new loading source appears in the catchment, the ENTIRE TMDL must be re-evaluated – inclusive of the serving of new regulations on polluters and modifications to monitoring and reporting programs. In essence, then, the effectiveness of TMDLs forms part of a long-term vision.

Nature and form of pollutants

The appropriate use of models requires that the nature, form and availability of nutrient elements and toxicants are known. Without this information, the use of models which, for example, predict TP concentrations or chromium, may over-predict the endpoints and result in overregulation and wastage of effort and expenditure (e.g. Lee, 2001). In the case of TP, for example, urban sources in South Africa are, typically, dominated by wastewater effluents, i.e. the TP component will be dominated by a fraction comprised of soluble reactive phosphorus (SRP). If the total loading and hence the TMDL is based on a high percentage of SRP then the model predictions are likely to be accurate. If, however, the bulk loading originates from agriculture, then much of the TP load may be in bound, non-reactive, particulate form and the use of a simple TP model will suggest load reductions that are likely to have little effect. Hence, use of the NEAP model in a stormwater or in an agriculturally dominated situation would incorrectly link unavailable forms of phosphorus to the indicator of beneficial use impairment.

Similarly, in the case of urban stormwater flows, trace metals are often present in bound, non-toxic forms that can be effectively managed by sedimentation and physical removal.

Against these arguments must be pointed out that good correlations have been demonstrated between TP loads and the level of algal biomass (for example the Vollenweider and other models, see OECD, 1982; Harding 2008) (see also Modelling). The relevance of certain models for use in South Africa has not been comprehensively assessed. Although some deterministic models have been used, these have been applied in the absence of any consideration of actual load:response assessments and, in most cases, applied without any specialist knowledge of, for example, phytoplankton response characteristics. As such, predicted *vs* observed comparisons are of limited value.

In summary, the consideration of 'pollutants', i.e. substances that impair aquatic life and hence the beneficial use of water resources, must be properly defined and technically valid. Reaching this endpoint requires high costs and dedicated specialist input from multi-disciplinary teams.

Overriding EPA viewpoints

One of the challenges to the TMDL approach is that much of the science behind it has been undertaken by EPA scientists, i.e. the inference exists that contrary scientific viewpoints have been excluded, deliberately or otherwise (Karr and Yoder, 2004). This is a weakness of many environmental regulation tools development by government or federal agencies, not least in South Africa. Furthermore, while there has been insistence on developing Ecological Reserves very few, if any, have been subjected to implementation monitoring and assessment.

1.5 SPECIFIC CHALLENGES TO THE TMDL APPROACH

The need for biological assessment and criteria

Karr and Yoder (2004) have argued that the TMDL approach is fatally flawed, based on the dependence on physico-chemical criteria and less attention to the use of biomonitoring. Their argument has considerable validity in that "*monitoring should improve our understanding of the connections between stressor, exposure and response gradients*".

This is not possible with physico-chemical monitoring alone as chemical assessments may lead to interpretation errors if biological criteria are not included. Additionally, as currently formulated, TMDLs underestimate consideration of non-pollutant influences such as flow alterations, loss of riparian areas, physical habitat alteration and the introduction of alien taxa.

Karr and Yoder recommend that in order to improve TMDLs, the following key actions should be implemented:

- A biological focus should be restored [the term 'restored' is used as in the mid-1900s when the use of biological criteria such as diatoms was already commonplace in the USA, e.g. Patrick 1997];
- Link stressors to gradients of biological response (see **Figures 3-5**) (see **Note 2**);
- Align policies with scientific advances (i.e. use the best tools available even if reliance on a less-discerning tool has been the status quo for a long time);
- Align quantitative models with ecological concepts.

Importantly, Karr and Yoder recommend that the agency involved with enforcing compliance (monitoring) also be tasked with monitoring the environmental response (= resource condition). In South Africa, both tasks would – in theory – devolve to the Department of Water Affairs (DWA) or their designated agent. However, it has become apparent that the DWA would, in its current form, be unable to undertake these tasks at the resolution required for TMDLs and that a specialist agency (= Third Party) would need to be appointed. While a counter-argument may be that the responsibility should fall to the Catchment Management Agency (CMA), this is an arguably unlikely scenario in the short to medium term.

An example of a stressor identification approach is provided below and in **Tables 1-2 and 1-3**:

- A checklist should be compiled that includes all potential stressors previously identified for Virginia (This should be considered a starting list, with other site-specific potential stressors added as needed).
- Under each potential stressor, a list should be compiled of all data sources that are applicable to this stressor, fully acknowledging that data availability varies greatly from watershed to watershed.

- Also, under each stressor, a list should be provided of any relevant standards, criteria, screening values, or other reference values that have been used, or might prove useful, in evaluating observed data for any given stressor.
- Sufficient justification should be provided for the rationale used in selection of the most probable stressor(s), and developed in cooperation with a local watershed technical advisory committee and DEQ.
- A detailed explanation of the stressor identification process should be presented to the local TAC for their discussion and concurrence and presented either as a separate Stressor Analysis report or as an appendix to the full report, while a summary of major points in the process should be included in the TMDL study report and presented in layman's terms at public meetings. It is important for the TMDL developers to effectively communicate with the stakeholders the reasoning for choosing or eliminating each potential stressor. Therefore, proper documentation is a major component of the report.

Table 1-2: Example of a stressor analysis identifying a single stressor

Stressor	**Screening Procedure**	**Criteria/Reference Database**	**Outcome**
pH	Field Measurement	VAWQS for Class III waters	Eliminated
Temperature	Field Measurement	VAWQS for Class III waters	Eliminated
Organic Chemicals-dissolved	Sampling, Fish tissue sampling	VAWQS-Acute or chronic criteria, Risk based Fish Tissue Screening Value	Eliminated
Organic Chemicals-Sediment	Sampling	DEQ 2006 assessment guidance memorandum	Eliminated
Metals- water column	Sampling, Fish tissue sampling, known sources	VAWQS- Acute or Chronic criteria, risk based fish tissue screening value	Eliminated
Toxicity-Ammonia	Sampling, chronic toxicity testing (mortality and reproduction) on fathead minnows and C. *dubia*. Growth testing on fathead minnows	Statistical Analysis	Eliminated
Dissolved Oxygen	Ambient data, Diurnal D.O. field measureement	VAWQS - minimum Standard	Non-stressor
Nutrient Nitrogen/Phosphorus	Diurnal DO monitoring, known and potential sources, biological field notes, total phosphorus andTotal Nitrogen sample analyses	Total Phosphorus median from the 2005 VA-DEQ nutrient criteria report, VADEQ reference values, EPT scores, MFBI scores, N/P ratio	Most probable Stressor (phosphorus)

Note 2: The linking of the pollutant driver to the biotic response is an important and central consideration. For chlorophyll, for example, the overall aim may be to reduce the nutrient driver to a level where the frequency of noxious algal bloom occurrence is at or below an acceptable level (e.g. Havens and Walker 2002). This same approach accompanied the development of the NEAP model for South Africa (Rossouw et al. 2008).

Table 1-3: Example of a stressor analysis identifying multiple stressors

Stressor	Screening Procedure	Criteria/Reference Database	Outcome
Temperature	Field Measurement	VAWQS	Eliminated
Organic Matter	BOD5, TKN	BOD5 and TKN background values for swamp-like streams	Possible Stressor
Sediment	Value for Habitat, TSS	None	Possible Stressor
Toxics	Sampling, Fathead minnow Acute and chronic effects, groundwater contamination	Acute/Chronic WQS, Virginia Groundwater Standard, MCL for chloroform	Possible Stressor
pH	Field Measurements, eutrophication of Bryant Pond, Dissolved Oxygen measurements	Class VII WQS	Most Probable Stressor
Nutrients	Dissolved Oxygen field measurements, algal growth in Bryant Pond, possible and known nutrient/dissolved oxygen violation sources, TP concentrations, Nitrite-nitrate-nitrogen concentrations	Class VII WQS for D.O., VADEQ Screening level, USEPA screening level, maximum concentrations, PLE, SPP threshold, State 99th and Coastal Plain Streams 100th percentiles for TP, Scientific Literature (Mills et al., 1985, VA-DEQ 2004a, Miltner and Ranking,1988, Sheeder and Evans 2004) RBII Index Scores	Most Probable Stressor
Dissolved Oxygen	D.O. field measurements, algal growth in Bryant Pond, possible and known nutrient/dissolved oxygen violation sources, nutrient sources	Class VII WQS for D.O.	Most Probable Stressor

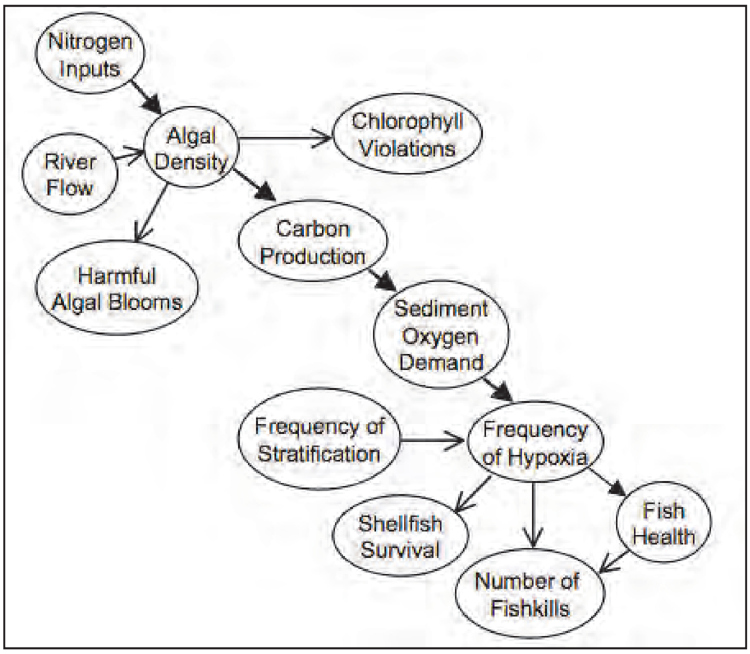

Figure 1-3: Diagram showing the linkages and sub-stressors related to nitrogen loading and fish.

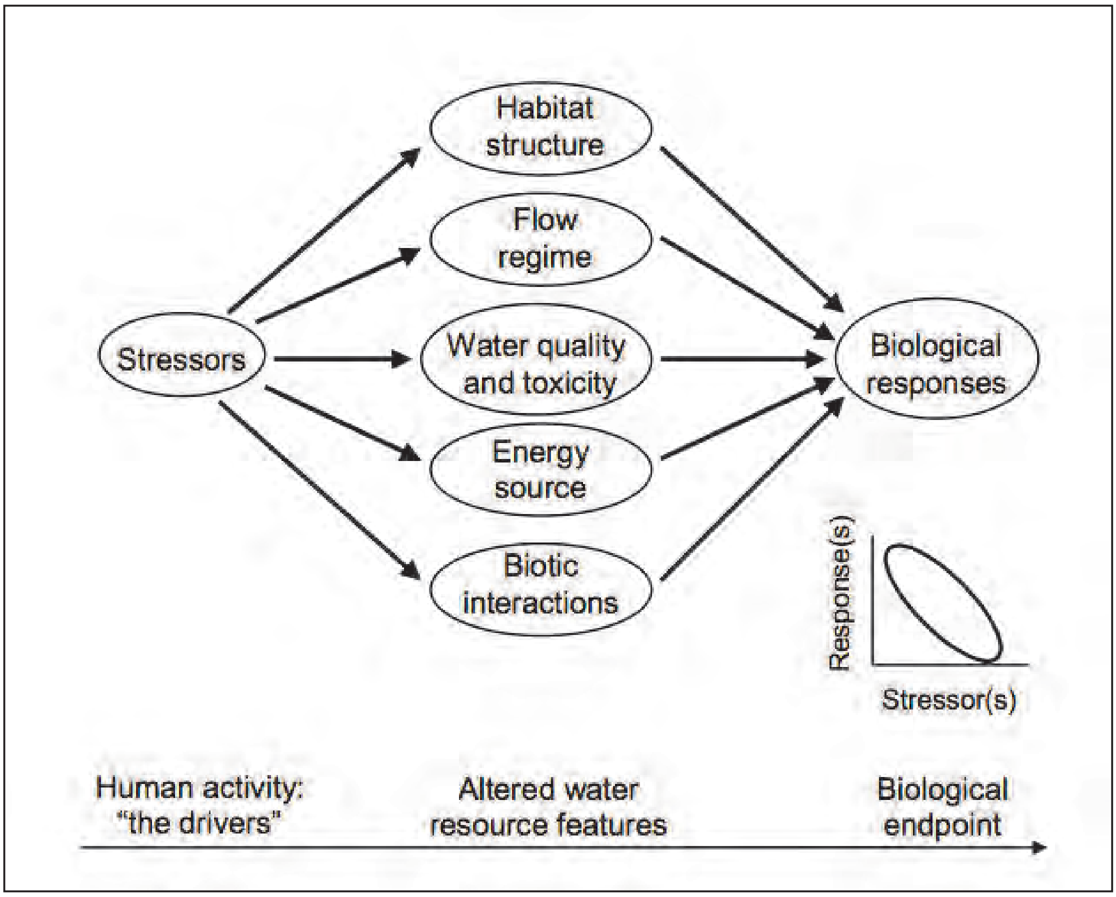

Figure 1-4: Linkages from human activity (the stressors or drivers of change) to major water resource features.

In Figure 1-4, linkages from human activity (the stressors or drivers of system change) through the five major water resource features altered by human activity, to the biological responses producing ambient condition, i.e. the biological endpoints of primary interest in biological assessment programs, are shown. This model illustrates the multiple causes of water resource changes [that underpin biological integrity] associated with human activities. The insert illustrates the relationship between stressor does and the gradient of biological responses that signal a good biological metric. (from Karr and Yoder, 2004).

The need to correctly link cause and effect, taking into consideration of any related “knock-on” effects, cannot be over-emphasized. Consideration of a single aspect in isolation can lead an entire TMDL being invalidated.

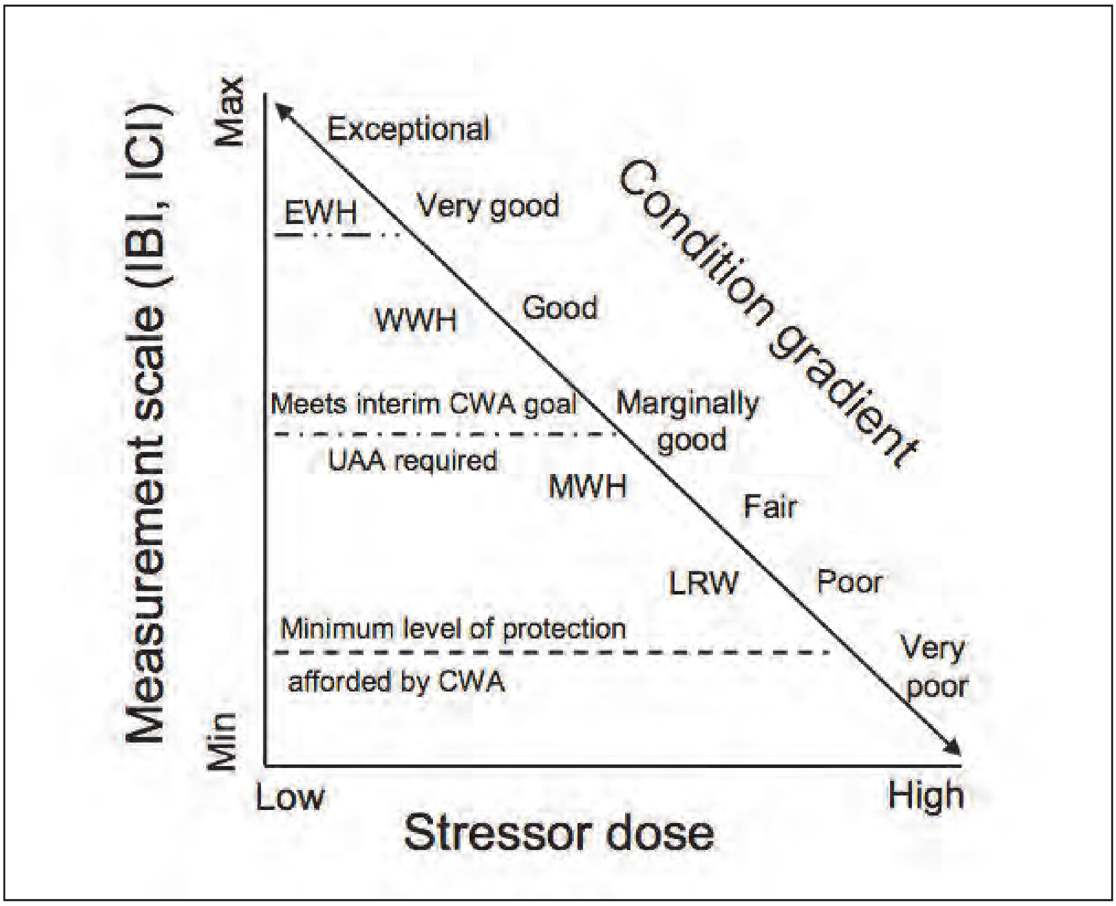

Figure 1-5: Relationship between stressor dose and biological measurement scale.

Figure 1-5 illustrates the relationship between stressor dose and biological measurement scale, such as the Index of Biotic Integrity (IBI) or invertebrate community index (ICI), showing the level of biological condition (exceptional to very poor) and associated aquatic life designated uses (exceptional warmwater habitat, EWH; warmwater habitat, WWH;

modified warmwater habitat, MWH and limited resources waters, LRW) as defined by the Ohio Environmental Protection Agency (from Karr and Yoder, 2004).

1.6 THE USEPA "TWENTY NEEDS" REPORT

The science-based limitations to effective implementation of the TMDL approach are clearly apparent and not inconsiderable. Approximately a decade ago, the USEPA commissioned a report to identify the twenty most important science needs related to the process (USEPA 2002). This report was based on internal (EPA) and external (practitioner and stakeholder) input:

Twelve of the twenty needs related directly to TMDL implementation and the remainder to policy-related issues (which fall beyond the scope of this review). The twelve issues (numbers 4-12 & 17-19 per USEPA 2002) are summarized as follows:

1. **Increase [the] quantity and quality of completed TMDLs**. Over 41,800 impairments affecting approximately 20,000 water bodies were reported by states in 1998. Most states lack the resources needed to develop and implement so many TMDLs. Although having EPA researchers do large numbers of TMDLs would be an impractical use of research resources, selective Office of Research and Development (ORD) involvement makes sense for practical researcher experience, pilot studies transferrable to similar sites, and in difficult or high-profile TMDLs. Indirectly, ORD may also help increase TMDL production by developing highly efficient modelling and monitoring tools.
2. **Improve watershed and water quality modelling**. The core of a TMDL is usually a model, and the quality of modelling is one of the essential factors determining the quality of nearly all TMDLs. Yet, modelling in TMDLs is widely criticized. Areas of weakness include: applied modelling technical support, availability of low- to moderate-complexity products, gaps in model applicability, model maintenance, and training. For better technical support, EPA might revitalize its support centres, increase their availability to states, and produce more modelling technical guidance. Products of appropriate complexity might be aided by ORD/Regional collaboration on a practical "Toolbox" concept. Gaps, on the other hand, also call for further investment in modelling research and development of models that address more stressors, biological responses, and control action effects. Model maintenance critics suggest that thorough updating of not only model architecture but also the underlying

science would be of great value. And finally, an ORD/OW training program in modelling would significantly improve the quality of many states' TMDLs.

3. **Improve uncertainty analysis and statistical techniques for TMDLs**. Shortcomings in statistical technique[s], particularly related to quantifying uncertainty, need to be addressed in TMDL models and especially in listing decisions. The Margin of Safety (MOS) in TMDLs has usually been estimated subjectively rather than calculated. Limited data is often the cause but a lack of statistical tools, guidance and experience contribute to the problem. Detailed guidance on quantifying uncertainty in the form of MOS estimation tools would be valuable, as would broader statistical training on statistically assessing evidence of impairment, addressing data gaps and limitations, credible extrapolation techniques, and QA requirements for found data.
4. **Improve the science base concerning all stressors (pollutants and pollution) and their impacts**. The NRC report explicitly stated that "*The program should encompass all stressors, both pollutants and pollution, that determine the condition of the water body*." This point highlights a significant inconsistency between the Clean Water Act goal of the integrity of the nation's waters and the limited tools provided to bring about that goal. Given the Act's regulatory limits, it is particularly important that EPA research address the full range of stressors and impacts in order to provide an unbiased science base and a comprehensive understanding of impairment. Existing ORD approaches to stressor research are inclusive, and it is crucial that this comprehensive treatment of exposure and effects research be maintained.
5. **Address numerous stressor-specific issues identified through the Strategic Planning and Research Coordination (SPRC)**. Well beyond the scope of this summary document are thousands of more narrowly defined research needs connected to TMDLs, and many of these have been addressed in the SPRC process. The SPRC was convened to identify water quality science needs and jointly plan research for a 10-year time frame. TMDL-related chapters address watershed management tools, restoration and BMPs, modelling, sediments, nutrients, toxics, monitoring and assessment, diagnostics, and landscape ecology.
6. **Improve consideration of atmospheric deposition in TMDLs**. Increasingly, states are finding that atmospheric deposition of mercury, nitrogen and other pollutants can be a significant source of loadings. This requires attention to data and monitoring methods, atmospheric and cross-media modelling, and cross-research-area planning.

7. **Improve guidance for allocation development and methods to translate allocations into implementable control actions**. Once the linkage is made between pollutant sources and instream water quality, the available assimilative capacity is allocated among the watershed's point and nonpoint sources. Allocation is a critical juncture in the steps of TMDL development from modelling through implementation of point and nonpoint control actions. Social and economic considerations also complicate allocation decision-making. ORD activities such as alternative futures assessment, watershed risk assessment, modelling, sustainable ecosystems, socioeconomic and pollutant trading research are all potentially relevant.
8. **Improve information on BMP, restoration or other management practice effectiveness, and the related processes of system recovery**. As management practices are typically implemented under limited budgets, post-evaluation is often dropped despite the fact that this is among the most widely cited needs. Practically every type of Best Management Practice (BMP) or restoration technique needs effectiveness research. Researchers must also consider that recovery of impaired systems is intimately linked to effectiveness, and recovery is not just the inverse of degradation. EPA's investment in effectiveness research is substantial, and ORD should continue to closely track the programs and practitioners who are their clients.
9. **Develop adaptive implementation approaches for doing TMDLs**. The NRC recommended that "TMDL plans should employ adaptive implementation.... foster the use of strategies that combine monitoring and modelling and expedite TMDL development." There is widespread agreement that adaptive management on a watershed basis is a sound and practical approach for TMDLs, but the need for more specific research remains. EPA researchers might develop or evaluate adaptive management strategies, or focus on related tools such as recovery forecasting models, post-implementation monitoring methods, and alternative futures analysis.
10. **Clarify and quantify selected parameters used in criteria definitions.** On this issue the NRC panel stated, "All chemical criteria and some biological criteria should be defined in terms of magnitude, frequency, and duration." Even beyond clarifying these three key parameters, criteria can and should go farther (in definition and in application) when necessary to establish a more reliable relationship between the designated use and the criterion meant to protect it. Temporal considerations are particularly in need of improvement, and regionalized syntheses of episodic stressor behaviour would be useful. Researchers might also address flows at which standards must be met, wet weather conditions, and sediment lethality.

11. **Develop and improve bio[logical]criteria, address other criteria gaps, and evaluate the potential for ecological water quality standards.** Standards and criteria still fall short of adequately representing, in just a few parameters, complex watershed ecosystems and the multiple uses they sustain. EPA researchers should undertake an exploratory reinvention of ecologically-based standards in the interest of better linkages among watershed management, designated uses, criteria, and measurements of watershed condition. ORD should also continue to assist progress on new types of criteria that are more ecologically relevant including biocriteria, habitat, sediment, and channel/riparian structure. EPA regional feedback has placed biocriteria development among states' greatest needs for new criteria and cited pathogen criteria among the most in need of refinement. EPA researchers should support and participate in the ongoing bioassessment program framework development effort. Other criteria development and refinement needs concern sediment dynamics; stream and riparian habitat; flow; relating fish advisories to numeric criteria; estuarine water quality standards such as marine DO and nutrients, coral reef-related standards; water quality standards for intermittent streams; wildlife and invasive species, wetlands, and new chemicals.
12. **Evaluate defensible scientific standards for listing and de-listing.** Specifically, the NRC panel's recommendation of a two-part impaired waters list (preliminary and final lists) has implications for monitoring research, sampling methods development and statistical analysis, usually occurring in a data-limited environment. Strengthening the scientific basis might include statistical guidance for listing decisions, methods for combining multiple lines of evidence (e.g. biomonitoring and chemical monitoring), improving the analysis of the role of flow as ultimately affecting the designated uses, and methods for uncertainty analysis.

The issues listed above effectively summarize the constraints that would face roll out of a TMDL – or any related approach – in South Africa viz. paucity of relevant data, minimal knowledge of dose:response characteristics over a range of water qualities and hydromorphological characteristics, lack of relevant skills and a lack of funding to effectively address any of the aforementioned limitations.

In a 2007 case-study review, the USEPA addressed six issues that constrain TMDLs in one manner or another, these being (USEPA 2007e):

1. How does variation in the availability, quality and analysis of data influence the development of useful, high-quality TMDLs?

2. How does variation in funding, guidance and leadership influence the development of useful, high-quality TMDLs?
3. How do variations in stakeholder involvement influence the development of high-quality TMDLs?
4. How do variations in scale and scope of the TMDL influence active stakeholder involvement and the production of useful, high quality TMDLs?
5. What elements of an implementation plan are most important for effective implementation?
6. How might EPA refine its TMDLs to further increase WQ decision maker knowledge and commitment to water quality improvements?

Note 3: It may be confidently argued that all of the above issues would be as relevant to the South African application of TMDLs as they are in the USA. Paramount here will be the need to rebuild skills sets of expertise in reservoir limnology.

In summary, the Twenty Needs survey concluded as follows:

1. Comprehensive, high-quality data availability is of paramount importance. Data for source loadings and runoff quality were adequate in less than 30% of cases. Data availability was a major constraint to the support of TMDLs. Insufficient data lead to increased use of modelling with consequent lowered level of confidence in the outcomes. Concomitantly, the TMDL becomes open to legal challenge, i.e. of dubious enforceability.
2. Funding resources, guidance and leadership. Funding is required over many years if the use of a TMDL-based approach (or any similar approach for that matter) is to be effective. This is likely to be a major challenge to TMDL implementation. In the USA guidance and leadership was considered to be of a relatively high quality – but it should be borne in mind that this has developed over many years. In South Africa these aspects would need to be developed from the ground up.
3. Stakeholder involvement is a multi-faceted issue that is founded on how well the stakeholders (a) understand and (b) accept the need for TMDLs to protect water resources. For example, some stakeholders see TMDLs as a benefit, others see them as an unnecessary cost.
4. Scale and scope of TMDLs. Multi-component TMDLs were found to be more acceptable with stakeholders than considerations of single pollutants. TMDLs that do not have numeric criteria pose a challenge to stakeholder acceptance.

5. What aspects of the implementation plan are most important? Accurate quantification of source loads and clear, numeric quantification of targets were found to be central to stakeholder buy-in.
6. In terms of organization and staffing skills, the accessibility and availability of TMDL information to stakeholders was or major importance (= outreach strategy).

With respect to the involvement of stakeholders, the following statement provides a useful perspective:

Beyond the science, broad involvement in TMDLs also has sociological implications. Because TMDLs address all the sources of pollution, from industrial effluent to fertilizer runoff from homeowner lawns, the TMDL process requires delicate and dedicated attention to the science and sociology in each watershed. Every landowner and land user in a watershed is affected by TMDLs, and broad awareness and involvement are very important (Jarrell, 1999).

In line with the Karr and Yoder (2004) arguments, the following informal analysis provided by Dr JA Thornton, Wisconsin South East Regional Planning Commission, provides some insight as to the practicalities linked to the formulation and management of a TMDL (Dr Thornton is a retired aquatic scientist with a lifetime of experience in water resource management, including many years spent in South Africa and Zimbabwe).

> *TMDLs are one of those nice theories that do not work in practice. Yes, we can determine to some reasonable level of confidence the level of (primarily) nutrient input that will maintain inland lakes in an "acceptable" quality state, especially if defined by the fishable criterion... swimmable is more problematic, since full body contact is usually defined by a bacterial standard, and I am not aware of any lake and watershed model that generates this information (aside from the more complex simulation models, that is; there is no "Vollenweider" model for bacteria). As I see it, we can easily define a phosphorus load to maintain a waterbody in a mesotrophic state (or any other condition, for that matter). We can equally select a point in time, define the land uses and outfalls that contribute to that load, and divide these contributions into a "maximum daily load." The problem arises when a new actor enters (more so than when an old actor leaves) the watershed. At least in Wisconsin, we are seeing significant land use shifts, with a largely agrarian landscape giving way to an urbanizing landscape since the Second World War. These shifts may be accompanied by an initial increase in sanitary systems based upon onsite sewage*

disposal systems (septic tanks), and a later shift to public waterborne wastewater treatment systems. These latter facts alone have been adequate to maintain the trophic state of our inland lakes; in other words, most major lakes have not gotten any worse for the increased area of urban land coverage. TMDLs did not enter into this process, and are only now being developed for the majority of our watersheds.

TMDLs require a degree of monitoring for compliance and enforcement. This is expensive work, and many governmental programs have slowly faded away. (In contrast, the USA volunteer monitoring programs on our inland lakes remain popular and are increasing in number; these programs provide planners such as myself with the best available and longest term data sets currently available, even if for a limited number of parameters...). To this end, the truth probably lies in the middle, as suggested by Karr & Yoder, with a sampling program that includes use of physical, chemical and biological indicators. Such a program entails costs, especially for skilled analysts... a factor that mediates against the use of such comprehensive programs during times when government is cutting budgets!

The lack of monitoring data also has an impact on the setting of TMDLs. We honestly do not know much about the majority of our waters; extensive data gathering programs are generally short-lived (due to cost considerations) and time-limited in scope. Analysis of the available data takes time, and, consequently, a TMDL can only be determined for an historic condition of a watershed.

This brings me, at last, to the role of biota in the process. People drive our societal responses to both the definition of, and response to, declining water quality. In part the public perceptions are use-related, especially if the individual(s) involved are engaged in contact water sports. User surveys have shown, time and again, that the primary use of our waters as recreational resources is for passive viewing/aesthetic appreciation rather than active recreation such as swimming and boating. The presence of algae is often cited as a "pollution indicator" by swimmers, recreational boating enthusiasts commonly cite aquatic plants and/or flocculent substrates as "pollution indicators." In my experience, humans seem to have an interesting built-in "memory" of lakes as clear, blue landscape features, regardless of what the actual waters look like within their own ambit of experience. Working with communities in semi-arid southern Africa, I found that citizens would describe a turbid impoundment as polluted whether or not the waterbody was experiencing an algal bloom, simply based on the lack of clear water. This is a result that is not dissimilar to the result *obtained in temperate Wisconsin, where humic waters are frequently described as polluted based on the lack of clear water. Beyond the curiosity factor of these observations, both communities can articulate a desired water quality state. Minimum criteria include "being able to see one's feet when standing knee-deep/waist-deep in the water," the "absence of smells and odors," and similar observations that knowledgeable limnologists can translate into Secchi disc readings, hydrogen sulphide concentrations, etc. In both cases, these perceptions rarely dissuaded these same citizen respondents from utilizing the waters available to them (= behaviour); you have not lived until you see someone waterskiing through a blue-green algal scum, throwing up a plume of algae-laden water behind them.*

So, in conclusion, I respectfully submit that TMDLs are great in theory, but fail in practice because of their technical rigidity, intensive data needs, and divorce from human perceptions. Aside from that, they are great!

Regrettably, South Africa has not – certainly insofar as reservoir management is concerned, heeded the warnings regarding retention and development of an informed, institutional skills base or the need for fundamental research and monitoring to be continued (e.g. Ellis 1993; Ramphele 1998). Re-skilling the field of reservoir limnology will take time, effort and money but will become absolutely necessary in the very near future (Harding, submitted).

1.7 METHODS

The USEPA has been the driver of the TMDL process in the USA from the outset. As such all method development and protocols have derived therefrom and will serve to inform this assessment. The "protocol" documents produced in the late 1990s have, more recently, been augmented with supporting documents in the light of 'lessons learnt'. Key documents are detailed as follows:

Protocols

For this assessment three protocols were considered, these being for nutrients (USEPA 1999a), sediments (USEPA 1999b) and pathogens (USEPA 2001c). The steps (stages) of the development of a TMDL are summarized in **Figure 1**. The Oklahoma TMDL Practitioners Guide (Oklahoma DOEQ, undated) was found to be the best, user-friendly manual for establishing a TMDL and including worked examples. The overview prepared by Jarrell

(1999) provides a useful contextualization of the method and the need for it. The submission requirements for TMDLs are well-summarized in MPCA (2007).

Third-Party TMDLs

While the USEPA has led many of the TMDLs undertaken in the USA, the workload is substantial and the need for TMDLs to be developed by third-parties has developed (WEF 1994). Such a need is likely to prevail in South Africa as the State is unlikely to have the skills or resources available. A downside of this approach is that the cost of TMDLs is likely to be higher when third-parties are used.

Incorporation of biological criteria

As discussed above, the need to use bioindicators in addition to water quality parameters is of vital importance to the successful linking of dose (loading) and response parameters. The USEPA guidance manual for linking stressors to biological impairment will serve as basis for this assessment (USEPA 2000; see **Figure 1-6**).

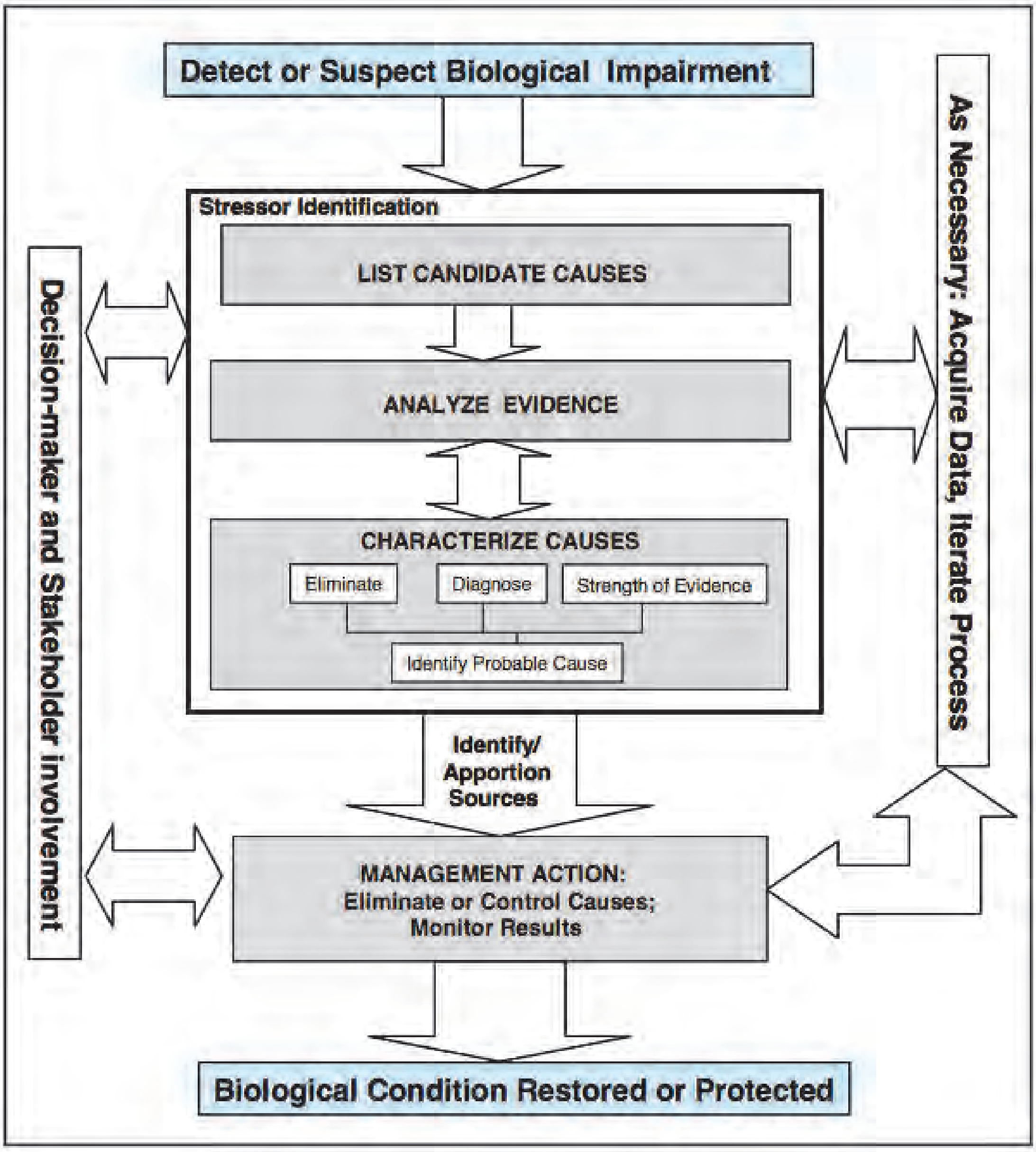

Figure 1-6: The stressor identification process (Source: USEPA 2000)

Deriving daily TMDL expressions from non-daily data

Many TMDLs have been developed as annual or seasonal rules, as opposed to shorter timeframes. The reasons for this should be readily apparent from the preceding review of the constraints. USEPA 2007b provides a detailed synthesis of the approaches available for specifying the TMDL as a series or range of daily expressions (see **Figure 1-7**).

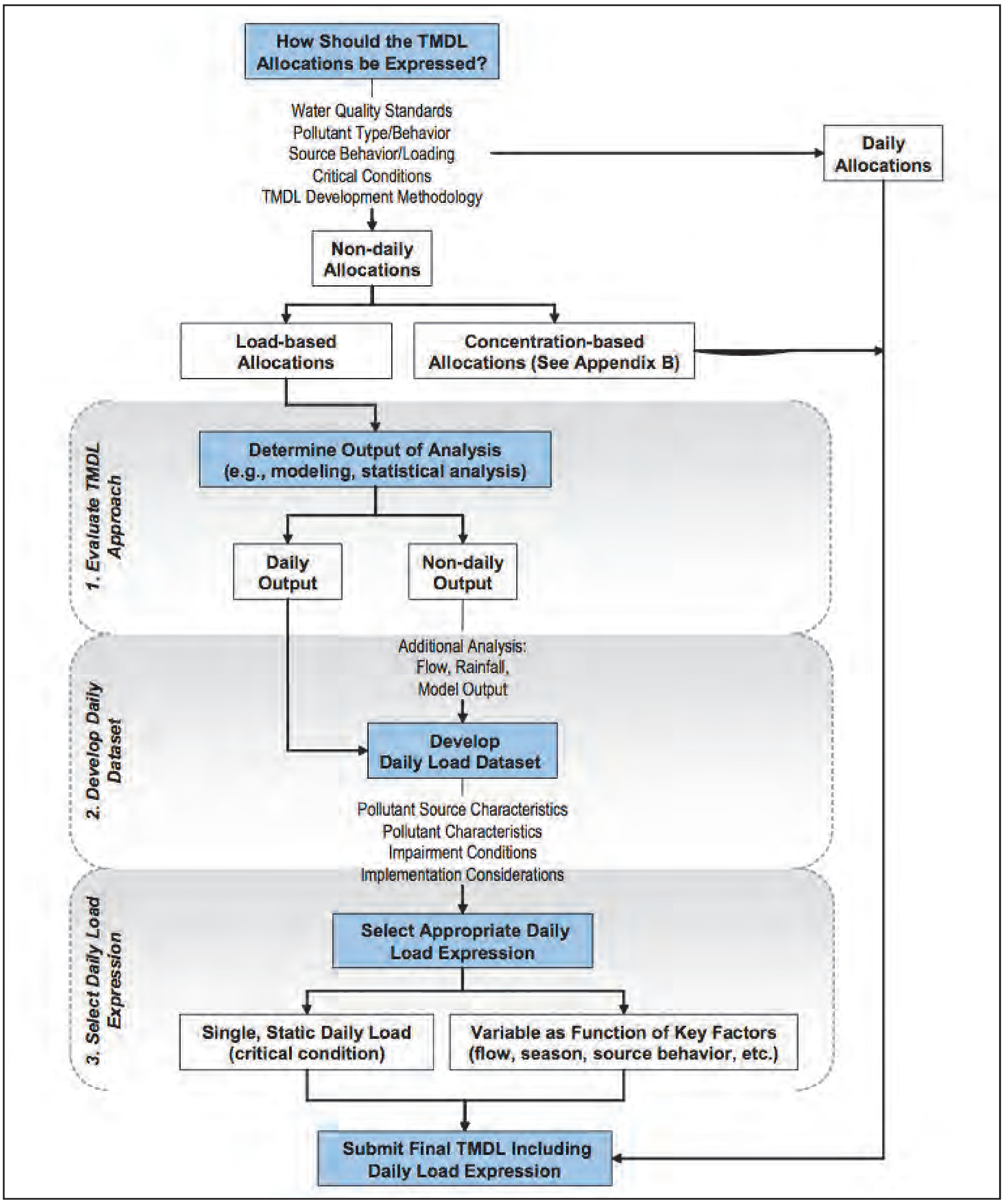

Figure 1-7: Process for deriving daily load expressions from non-daily analysis (Source: USEPA 2007b)

Incorporation of flow-duration curves

Derivation of short timeframe TMDLs makes use of data derived using flow-duration curves, an application informed by USEPA 2007c. The development of the related regression equations is detailed in USGS (2003). Estimating low flow statistics for streams is described in Ries and Friesz (undated).

Statistical analyses

Useful guidance documents for sample program design and data handling are USGS (2001), USEPA (2002c), USEPA (2006), Robertson et al. (2008) and Washington State (2012).

1.8 EXAMPLE TMDLs

Hundreds of TMDLs have been derived in the USA, mostly during the past 15 years. This review considers examples of nutrient, trace metal, sediments, sulphates, PCB and bacterial TMDLs. The following examples were sourced and use to inform this assessment:

Bacteria: (USEPA 2005); Nutrients: Ammonia (Pelletier 1993); Nitrogen (USEPA 2002); Phosphorus (Load reduction goals for lakes, Fulton and Smith 2008); Phosphorus (USEPA 2007d, MPCA, 2010); Sediments (USEPA 2001b); Sulphates (TCEQ 2007, Walker Associates 2007, USEPA 2011b and multi-target TMDLS (e.g. USEPA 2012).

A wider range of examples may be sourced from the USEPA website (see link following):

http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/examples_index.cfm

TMDL Implementation Guidance

The Department of Environmental Quality in the State of Oregon has produced a manual for the implementation of a TMDL, i.e. to guide the necessary actions, following the drafting and approval of a TMDL, required to improve water quality (ODEQ, 2007). A similar document has been produced in Virginia (VDEQ 2003). In the anticipated South African context, these actions would be carried out by the Catchment Management Agency (CMA).

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2 CASE STUDY SELECTION

2.1 INTRODUCTION

This project is a feasibility study that will attempt to assess the degree to which the Total Maximum Daily Load (TMDL) approach could be applied in South Africa using available data and information. In this regard the constraints to formulating TMDLs, as identified in Section 1, need to be borne in mind. Additionally, this project intends to identify any acceptable variation(s) of the protocol that would allow its use in modified form, despite identified limitations. It is accepted that each individual TMDL assessment is case specific and thus that this project cannot be comprehensive.

The selection of case studies (CS) encompassed:

1. Identify CSs that will test all of the issues and constraints as identified (see Note 1);
2. Examine, using GIS, the availability of matched water quality and hydrological data for each CS;
3. Acquire all available data necessary to undertake the further development of TMDLs or derivatives thereof for each CS;
4. Establish links with the relevant departments and local authorities located within the CSs (this task was undertaken utilizing the Letter of Introduction provided by the WRC);
5. Transfer all available information to GIS;
6. Identify and address any additional data limitations or gaps identified in (5).

The CS were selected based on their location within easy travelling distance from the offices of the project leader, i.e. within the project budget, the availability of data required to fulfil the requirements of the TMDL protocol, variation in landuse, i.e. CS's with a broad contrast between urban and agricultural sources of pollution and areas where existing issues in terms of water resource quality and management have previously been identified and which currently present a constraint to water resource-related development.

<u>Note 1</u>: **The purpose of this project is not to provide solution to specific loading:response issues; rather the purpose is to test the TMDL methodology *per se*.**

The following two Case Studies were selected:

1. The Berg River catchment, between the source and Misverstand Dam;
2. The Riviersonderend River between the source and Theewaterskloof Dam.

2.2 CASE STUDY BACKGROUNDS

Berg River

The quality of the upper Berg River is significantly impaired by urban runoff and wastewater effluents and has been for a long time (e.g. Bath 1989). This impairment has resulted in the initiation of the Berg River Improvement Program under the auspices of the provincial Department of Environment Affairs and Development Planning (DEADP), i.e. a program that could draw immediate benefit from a TMDL-based assessment of the sources and levels of nutrient loading. A variety of TMDL rule options present themselves, both for the Berg River as well as for the Misverstand Dam located at the downstream end of the Case Study Area (CSA). Additionally, options to formulate TMDL rules for the Klein Berg River (a source of nutrient pollution to the off-channel Voëlvlei Dam) present themselves, as well as for the envisaged transfer of water from the Berg River to Voëlvlei (the Voëlvlei Augmentation Scheme). The Misverstand Dam has been previously identified as a water resource requiring attention in terms of nutrient loading and problematical cyanobacterial blooms (Harding, 2008).

The Berg River CS, encompassing the quaternary catchments G10A-J, provides a mix of urban and agricultural uses but with urban pollution predominant. Two large urban wastewater treatment plants, as well as several servicing more rural towns, are located within the CSA.

The Berg CS contains three large supply dams, (Berg River, Wemmershoek and Voëlvlei – all supplying water to the Cape Town Metropole) as well as the Misverstand Dam.

Data availability for the Berg River CS may be described as comprehensive for both the mainstem as well as the key tributaries.

Riviersonderend River

The Riviersonderend CS focuses on the Theewaterskloof Dam, Cape Town's largest source of raw potable water. The dam has been characterized by low-level blue-green algal problems ever since the late 1980s and more recently as eutrophic (Matthews 2014). The dam is particularly sensitive to nutrient pollution and, as such, presents a major potential threat to potable water supply and agricultural use in the downstream catchment should the conditions worsen.

In contrast to the Berg River CSA, the Riviersonderend CSA (quaternary catchments H60A-C) contains only one conurbation, Villiersdorp. There are two dams in the catchment, these being Elandskloof, NW of Villiersdorp and the Theewaterskloof Dam. There is a golf course estate on the eastern shoreline of Theewaterskloof Dam. Proposals to construct additional resorts and estates on the shoreline of the dam could impact negatively on its condition.

Data availability for the Riviersonderend CSA may be described as acceptable. Whereas the Berg CSA is dominated spatially by dryland agriculture, the catchment for the Theewaterskloof Dam is largely mountainous and undeveloped.

2.3 DATA COLLATION AND PRE-PROCESSING

All of the data have been evaluated, cleaned where necessary, tabulated and subjected to provisional assessment of trends ahead of their use in Deliverable 3. With respect to water quality, provisional data selection was made initially on the basis of a monitoring station being currently active. Thereafter a second selection was made on the basis of inactive stations that have only recently been rendered inactive or that are likely to render data that will characterize conditions in a particular sub-catchment. The same rules were applied to the selection of hydrological data stations.

DATA SUMMARY

Data were collected from the following sources:

- Department of Water Affairs (Hydrology)
- Department of Water Affairs (Water Quality WMS)
- City of Cape Town (Scientific Services)

- Drakenstein Municipality
- Stellenbosch Municipality
- Lyners Consulting Engineers
- Aurecon Consulting Engineers
- Department of Agriculture (Plant Protection)
- SANBI

2.4 CASE STUDY AREA SUMMARIES

Berg River

The extent of the Berg River CSA and the various data layers are shown in **Figures 2-1 - 2-5**. Water quality and hydrological data sites are provided in **Tables 2-1 and 2-2**.

Riviersonderend

The extent of the Berg River CSA and the various data layers are shown in **Figures 2-6 - 2-9**. Water quality and hydrological data sites are provided in **Tables 2-3 and 2-4**.

A fundamental difference between the two CSA's, and one that will inform the testing of the protocol is that whereas the Berg River CSA is amply supported by numerous, active data monitoring points on both the mainstem and key tributaries (see **Figure 2-10**), the Riviersonderend CSA is not. Accordingly, while it should be possible to directly compare the modelling of loadings using export coefficients to measured values in the Berg CSA, reliance on export coefficients will be central to the Riviersonderend study.

The Berg CSA, per **Figure 10**, provides an excellent match of hydrological and water quality data for key nodal points in the CSA.

2.5 INITIAL DATA SCREENING

Testing of the TMDL approach in the selected catchments will primarily focus on nutrients and in particular phosphorus. Other parameters may be added as the project develops.

The data provided by DWA were initially screened on five levels, as follows:

(i) availability of phosphorus data as ortho-phosphate P (O-P);

(ii) in addition to (i), co-availability of Total Phosphorus (TP) data sufficient to develop a relationship between ortho- and TP that can be used to predict TP at sites with only O-P data;

(iii) use of electrical conductivity (EC) data to pre-screen all the sites in terms their salt content;

(iv) cleaning of the data sets to remove obviously erroneous outliers;

(v) identification of the initial requirements for temporally-matching flows and concentrations at sites where flow and concentration data are available.

The summarized data sets are provided in **Tables 2-5 & 2-6**.

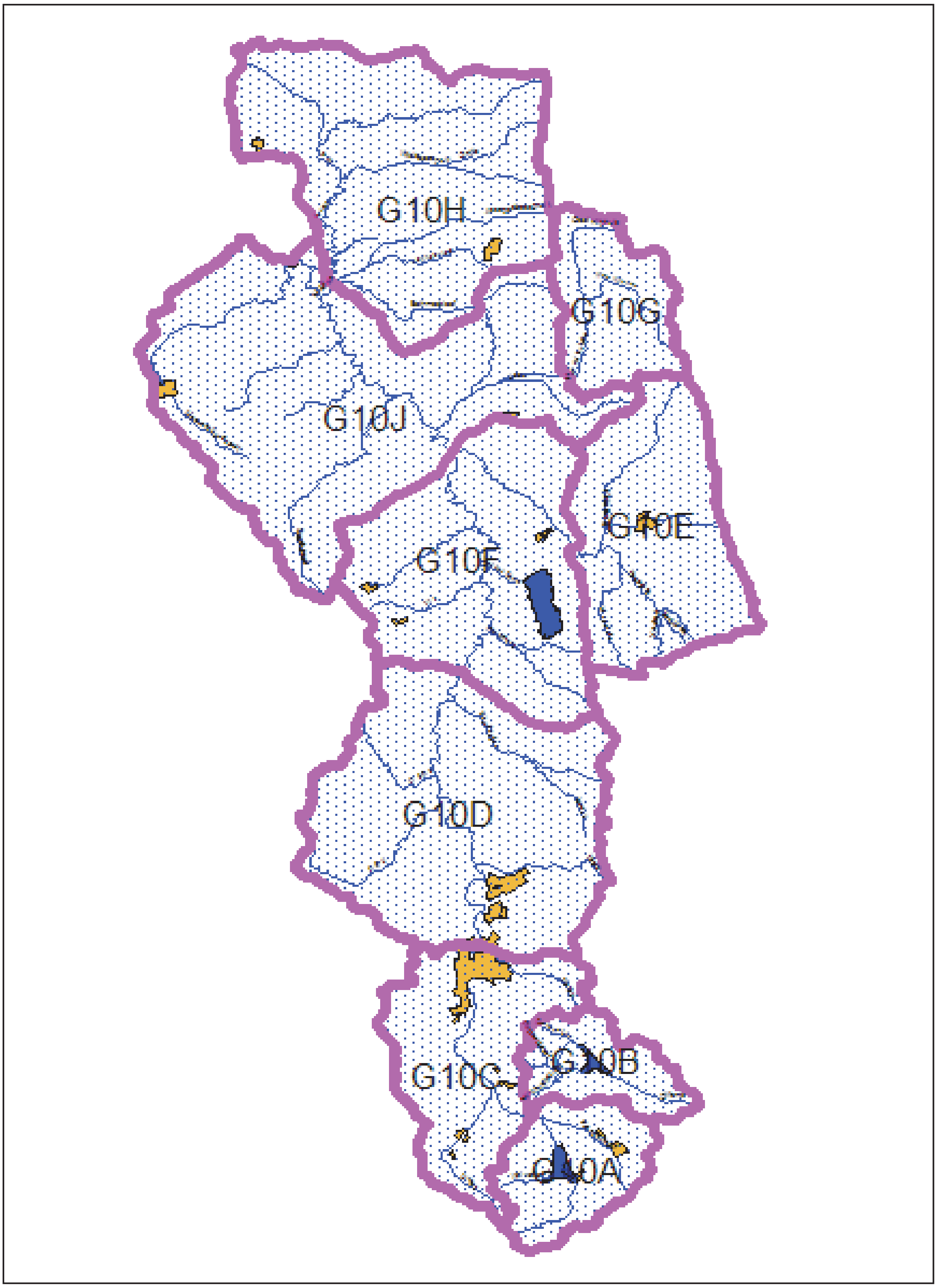

Figure 2-1: Berg River Case Study Area (see text for key)

Berg River CSA showing the major urban areas (yellow), the quaternary catchments (outlined in pink) and the dams (blue). Misverstand Dam is located at the outlet of the Berg River from catchment G10J (arrowed).

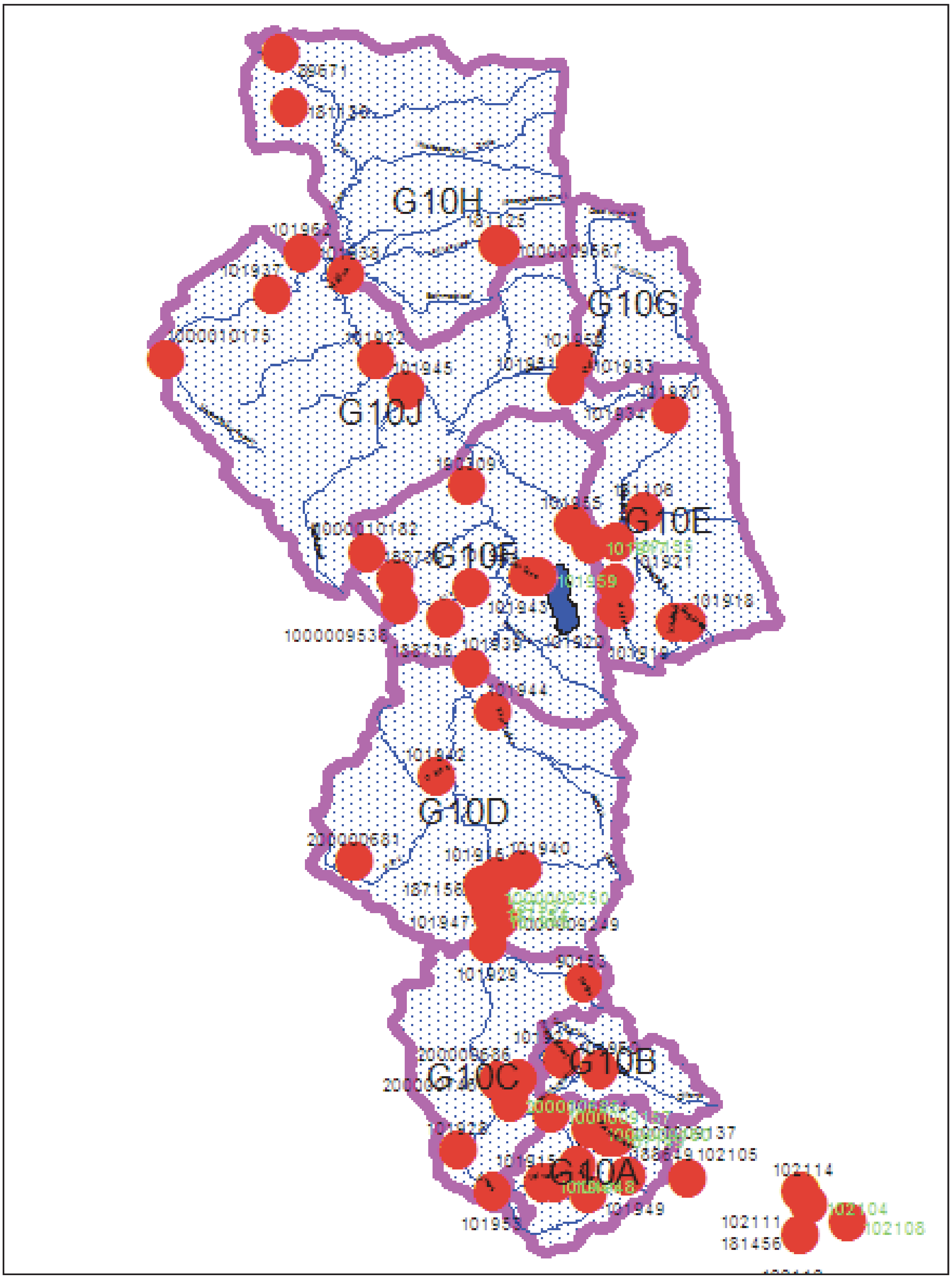

Figure 2-2: Berg RIver CSA showing all water quality monitoring sites

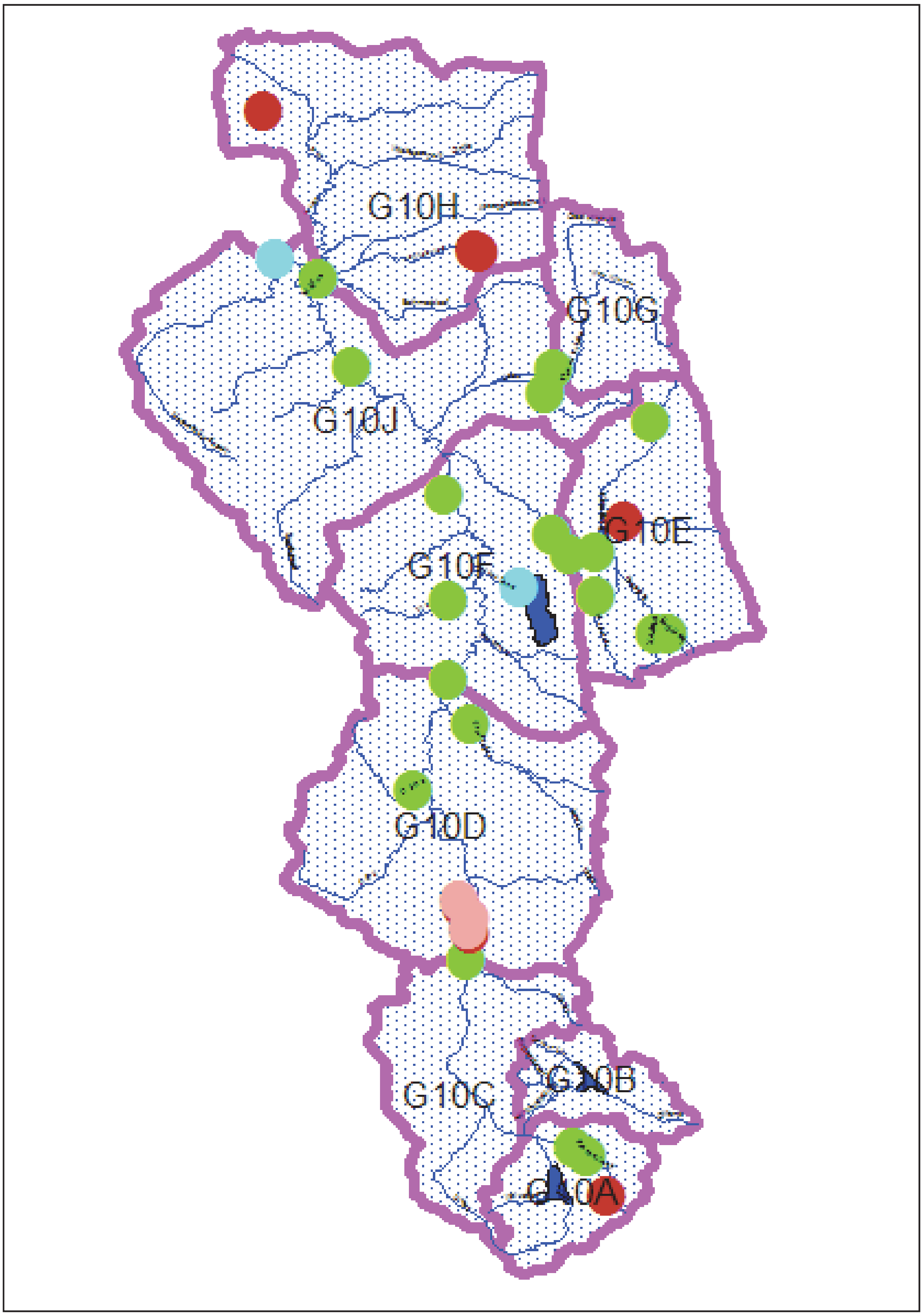

Figure 2-3: Berg RIver CSA showing selected water qualit nodes (see text for key).

Berg River CSA showing selected water quality monitoring nodes (red = wastewater treatment plant; green = river; blue = dam and salmon = bacteriological).

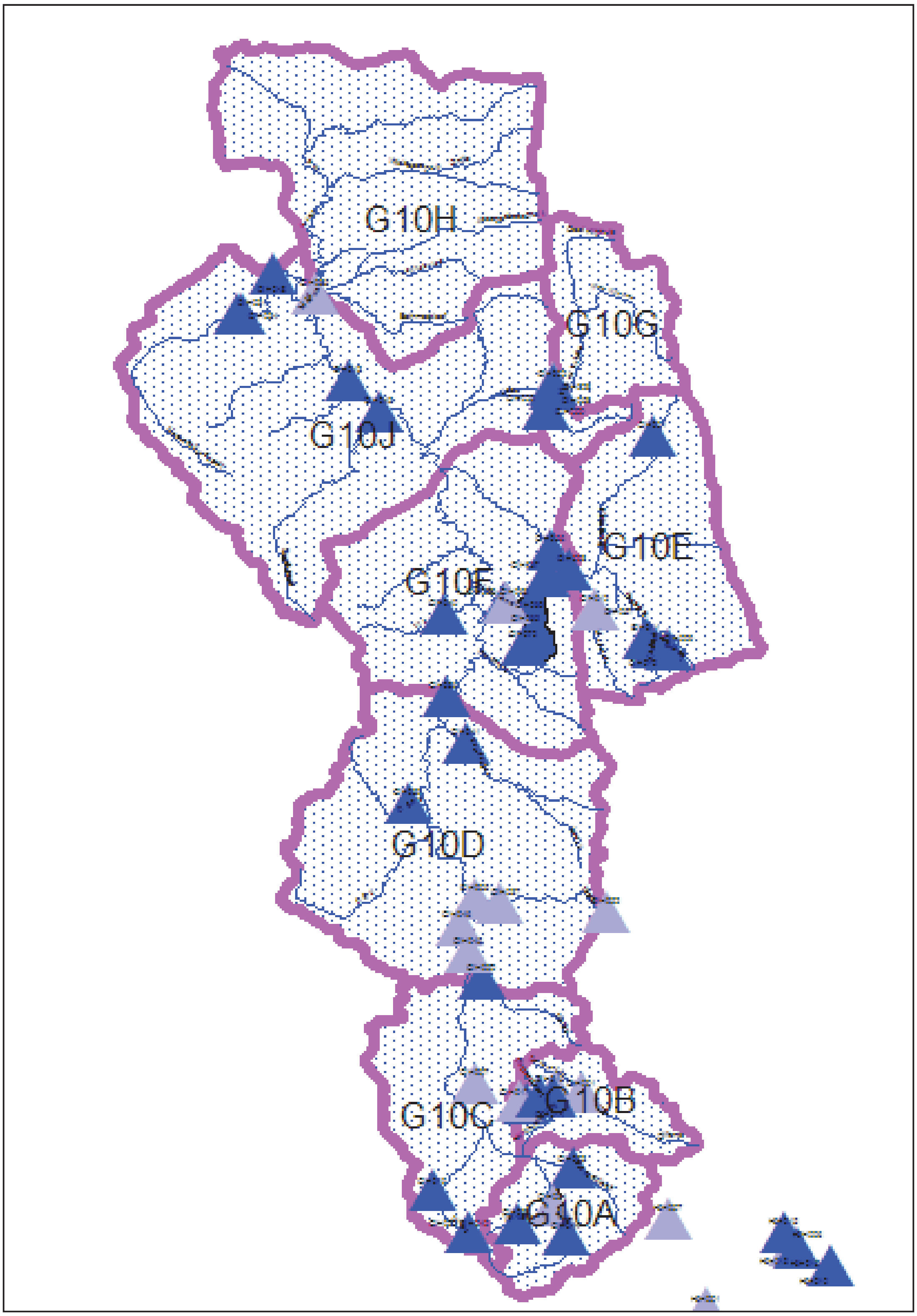

Figure 2-4: Berg RIver CSA showing hydrological stations (see text for key).

Berg River CSA showing the hydrological monitoring stations. Blue = active, grey = inactive. Stations for CSA 2 also shown.

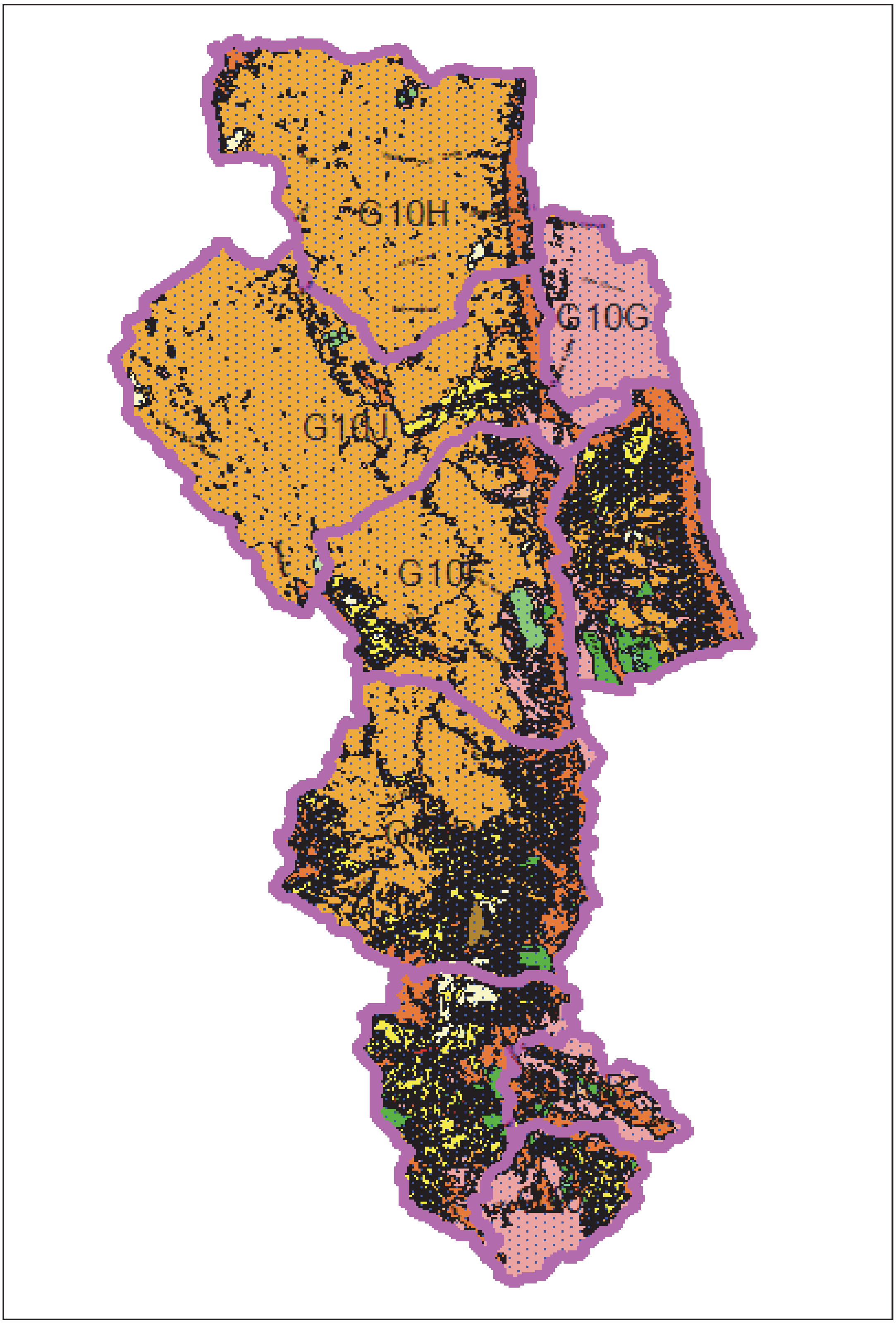

Figure 2-5: Berg RIver CSA landuse (30 m resolution)

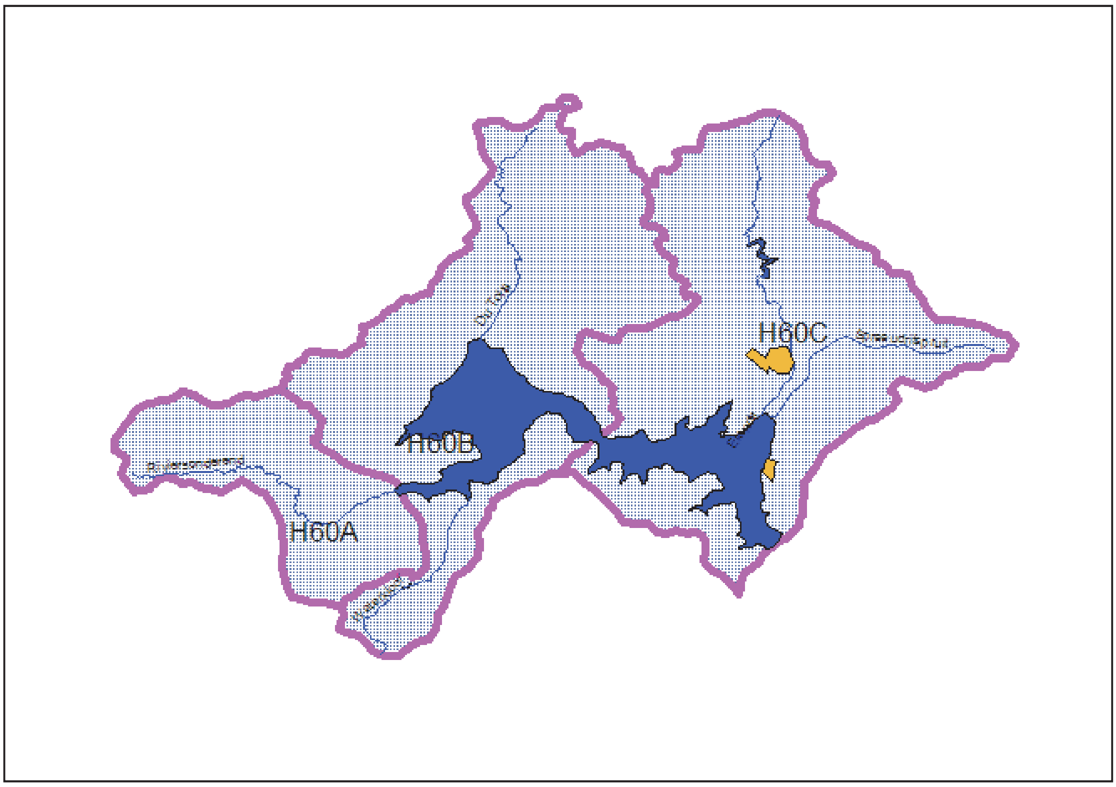

Figure 2-6: Riviersonderend CSA showing urban areas (yellow) and catchments (pink)

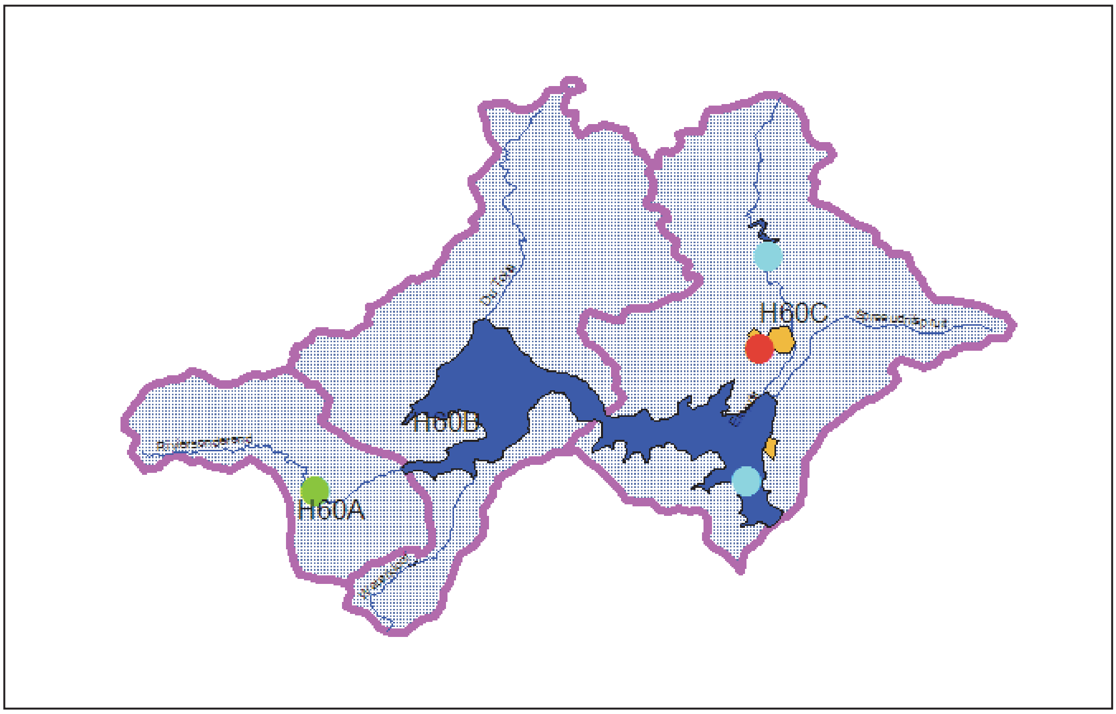

Figure 2-7: Riviersonderend CSA showing water quality nodes (see text for key).

Riviersonderend CSA selected water quality monitoring nodes (red = wastewater treatment plant; green = river and blue = dams.

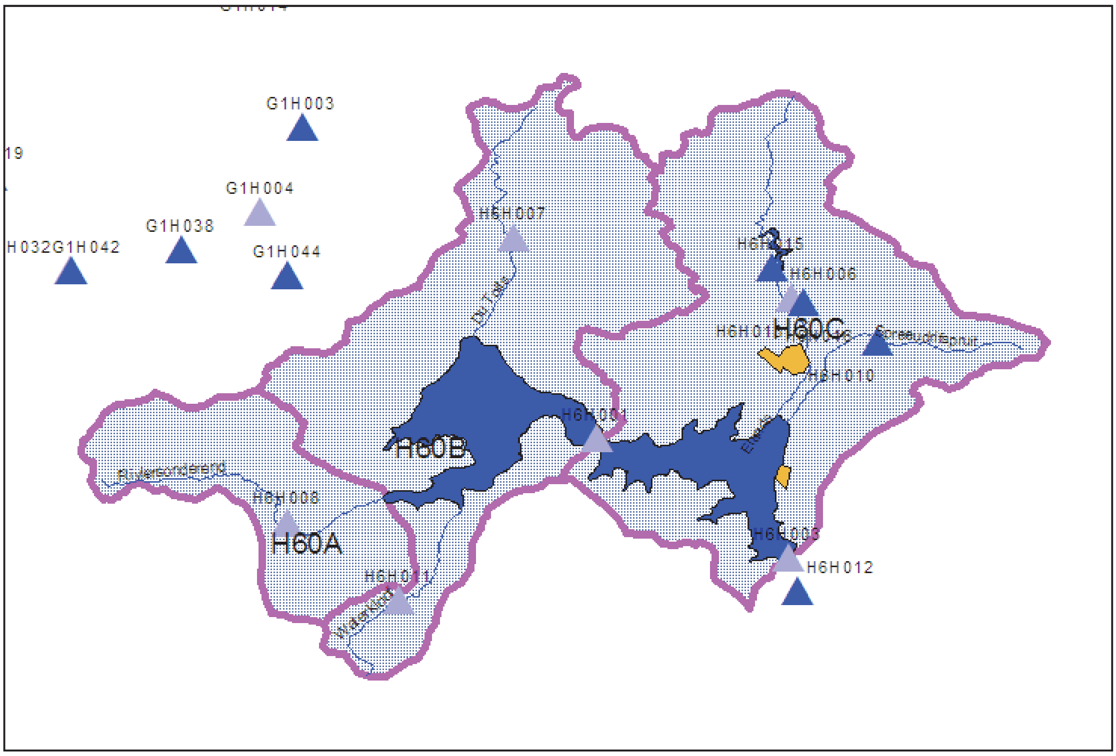

Figure 2-8: RSE CSA hydrological stations. Blue = active, grey = inactive.

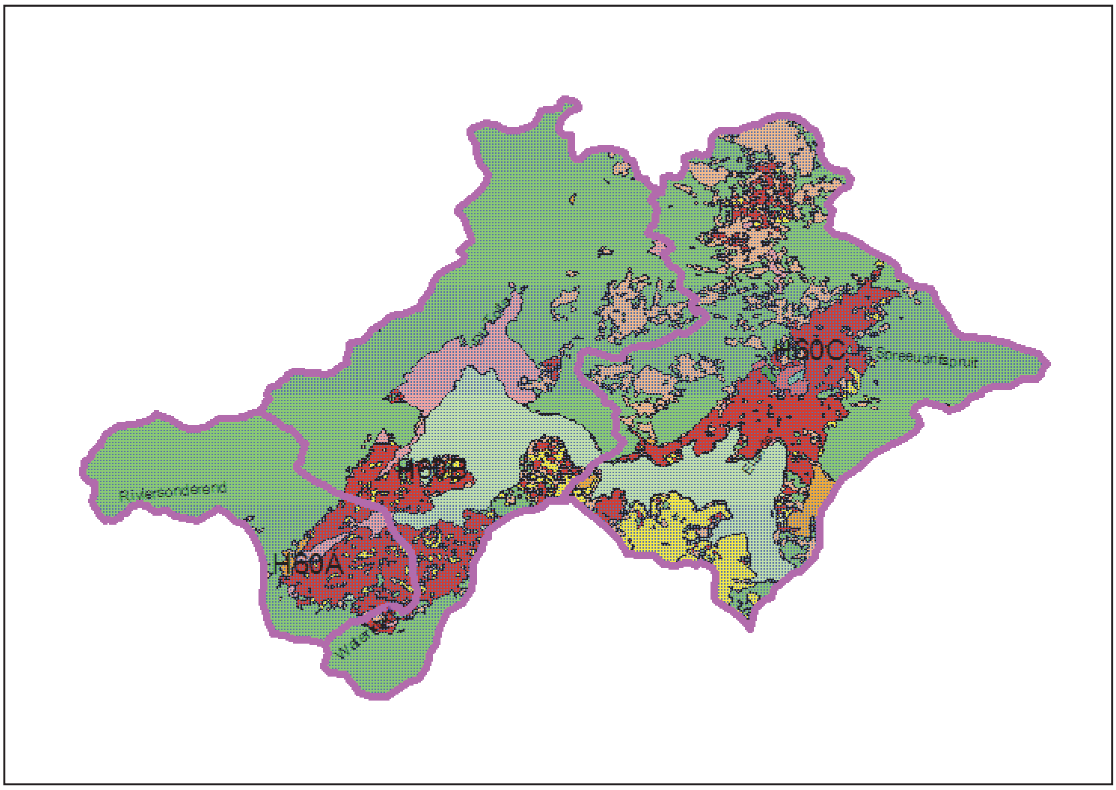

Figure 2-9: RSE CSA landuse (30 m resolution)

Table 2-1: DWA water quality sites for the Berg River CS

GIS#	WMS #	Description	Data span
1	187149	Franschhoek River d/s Stiebeuel	2003-present
3	188649	Swiss Farm WWTW	2005-present
4	101929	Berg River at Dal Josaphat	1965-present
5	101946	Paarl WWTW	1983-present
6	101947	Wellington WWTW	1983-present
7	101939	Berg River at Hermon	1978-present
8	101942	Doring River	1979-present
9	101944	Kompanjesrivier	1979-present
10	187154	d/s Paarl WWTW (faecal indicators)	2003-present
11	187156	d/s Wellington WWTW (faecal ind)	2003-present
12	187932	d/s informal settlements (faecal ind)	2004-present
13	101917	Kleinberg at Nieuwekloof	1955-present
14	101918	Brakkloof	1971-present
15	101919	Knolvlei	1974-present
16	101921	Watervals River	1977-present
17	101930	Kleinberg at Mountain View	1969-present
18	187155	Kleinberg at Tulbagh Bridge	2003-present
19	181106	Tulbagh WWTW overflow	1990-present
20	101955	Kleinberg canal to Voëlvlei Dam	1976-present
21	101959	Voëlvlei Dam	1969-2011
22	101943	Vis River at La Fonteine	1980-2012
23	190309	Berg at Saron	2004-present
24	101933	24 Rivers at Drie Das Bosch	1972-present
25	181125	Porterville WWTW overflow	1990-present
26	181130	Piketberg WWTW overflow	1990-present
27	1000009567	Voëlvlei Prison WWTW overflow	1994-present
28	101962	Misverstand Dam	1977-2010
29	101922	Berg River at Drieheuwels	1965-present
30	101934	Leeu River at De Hoek	1973-present
31	101938	Matjies River	1971-2012
32	101914	Franschhoek River	1966-2010

Table 2-2:Berg River hydrological stations.

G10 A-J	G1H019, G1H020, G1H036, G1H039, G1H041, G1H009, G1H010, G1H011, G1H008, G1H066, G1H067, G1H040, G1H059, G1H035, G1H031, G1H021, G1H003, G1H048.

Table 2-3: RSE CS water quality stations.

GIS#	WMS #	Description	Data span
1	102112	Theewaterskloof Dam	1980-present
2	102114	Elandskloof Dam	1977-present
3	181456	Villiersdorp WWTW to Elands River	1992-present
4	102106	Riviersonderend at Nieuweberg Forest	1967-1992

Table 2-4: RSE CS hydrological stations.

H60 A-C	H6H010, H6H015, H6H012

Table 2-5: Berg CSA, summarized water quality.

Site	Electrical conductivity, mS/m			Ortho-P as P, mg per litre			Total Phosphorus, mg per litre		
	Range	n	Median	Range	n	Median	Range	n	Median
101914	3.1-417	851	14.5	0-4.1	607	0.03			
101917	2.5-52	1148	18.6	0-1.1	1074	0.01			
101918	3.9-537	289	259	0-0.4	282	0.03			
10919	10.2-85	133	27	0-1.4	128	0.02			
101921	3.3-242	530	72	0-2.1	438	0.01			
101922	3.5-222	1501	24.2	0-3.01	1393	0.02	0.01-0.6	890	0.09
101929	0.5-42.6	1415	10.5	0-3.34	1296	0.02	0.03-0.6	82	0.09
101930	2.1-22	426	4.0	0-0.3	403	0.01			
101933	1.1-19.4	747	3.7	0-0.2	694	0.01	0-0.14	188	0.01
101934	2.5-15.9	594	4.7	0-0.33	540	0.01	0-0.23	187	0.02
101938	3.4-965	826	301	0-4.5	778	0.03	0-1.03	94	0.16
101939	6.5-112	1076	20.8	0-0.98	973	0.08	0-0.88	245	0.27
101942	9.6-1439	540	466	0-4.3	523	0.16			
101943	3.5-929	514	186	0-5.9	494	0.03	0.04-0.85	15	0.18
101944	7.4-868	989	11.4	0-0.85	936	0.02			
101946	12.1-126	1108	76	0-13.5	1081	4.03			
101947	6.1-189	1040	73	0-21.4	995	5.7			
101955	7.8-37	136	19	0-0.18	132	0.020	0-0.18	80	0.04
101959s	3-57	1099	9.0	0-0.63	1086	0.01	0-0.2	855	0.03
101959c	8-29	168	8.5	0-0.65	167	0.01	0-0.4	158	0.04
101962s	3.5-110	1058	35	0-0.35	1058	0.02	0-0.145	727	0.09
101962c	10-95	123	33	0-0.23	121	0.03	0.02-2.6	117	0.09
101186w	7-138	362	67	0.3-21	84	6.05			
181125w	41-178	183	77	2.2-16.6	53	8.5			
181130	0-876	252	100	0.23-37.1	48	10			
188449w	23-157	60	49	0-35.4	61	3.9			
9567w	10-100	254	41	1.1-6.7	44	3.6			
s = Reservoir surface sample; c = reservoir 0-5m integrated sample; w = wastewater effluent									

Table 2-6: RSE CSA, summarized water quality.

Site	Electrical conductivity, mS/m			Ortho-P as P, mg per litre			Total Phosphorus, mg per litre		
	Range	n	Median	Range	n	Median	Range	n	Median
102106	1.8-3.4	378	3.6	0-0.30	251	0.012			
102112s	1.5-49	494	8.3	0-0.36	447	0.013	0-1.78	15	0.03
102112c	7-11	13	8.5	0-0.09	13	0.01	0-0.11	11	0.03
102114s	4.6-15	397	7.3	0-1.48	357	0.01			
181456w	0-437	218	50	1-20	79	6.2			
s = Reservoir surface sample; c = reservoir 0-5m integrated sample; w = wastewater effluent									

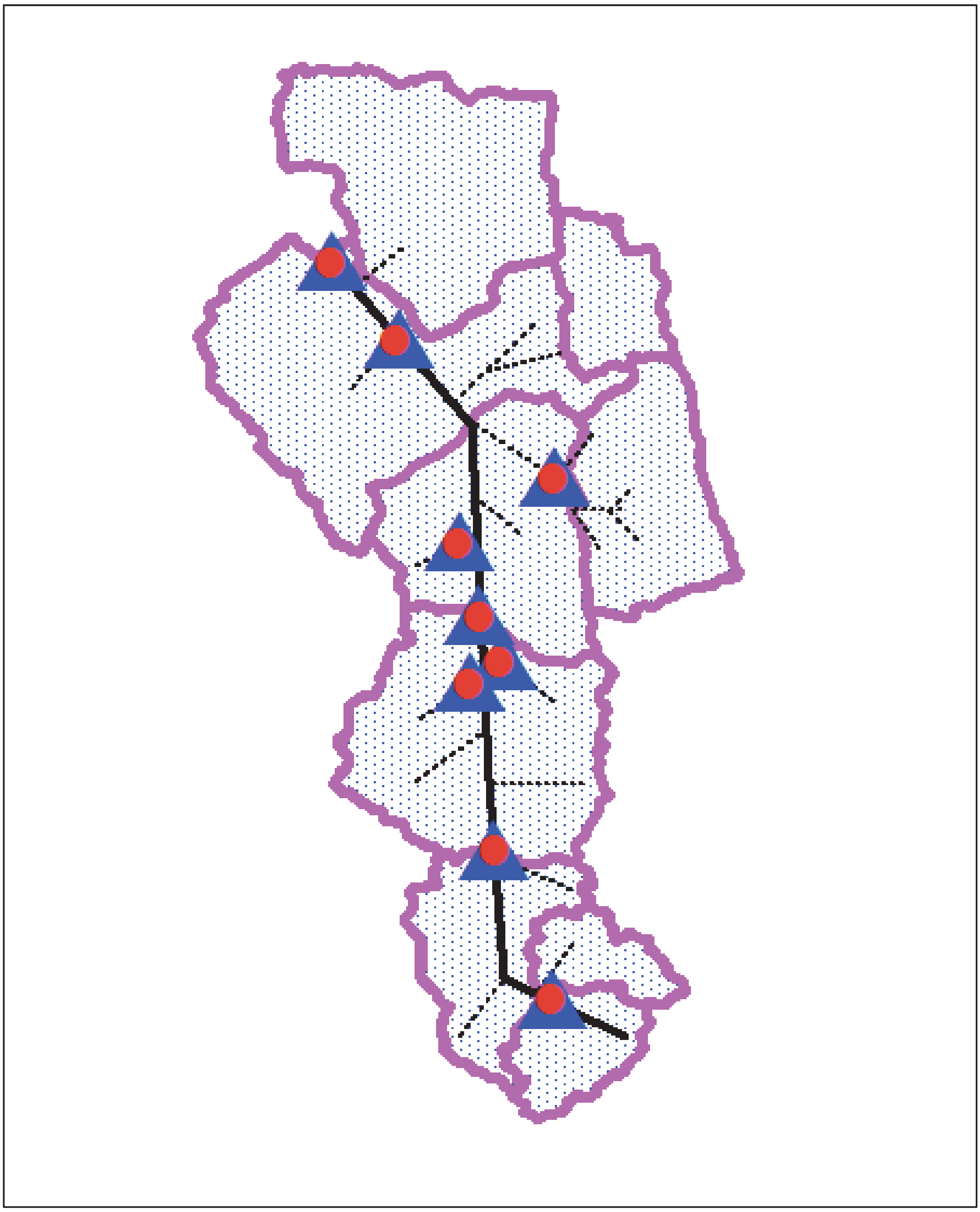

Figure 2-10: Line diagram of Berg River and tributaries.

In Figure 2-10, a line diagram of Berg River mainstem (solid black line) and major tributaries (dashed black lines) is overlain on the quaternary catchments for the Berg CSA. Matched water quality monitoring points (blue triangles) are overlain with the availability of hydrological data (red circles).

2.6 REFERENCES

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HARDING WR (2008) The Determination of Annual Phosphorus Loading Limits for South African Dams. Water Research Commission Report 1687/1/08. www.wrc.org.za. ISBN 978-1-77005-866-6.

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3 MODEL SCREENING

3.1 INTRODUCTION

The aim of this section was to identify and test existing models, or combinations thereof, which would facilitate the determination of pollutant loads at specific locations in a watershed. The overriding requirement for this feasibility study to make use of existing data dictated the eventual selection of model types.

The two case studies selected as per Section 2 define the two alternate ways in which TMDLs could be determined in South Africa, using existing information. For the purposes of this analysis these are termed the “Tree and Branch Method” and the “Export Coeffficient Method”.

Tree and Branch Method

The Berg River CS provides a good example of this method. The aggregate watershed being examined is characterized by a mainstem river, with a number of tributaries draining certain quaternary catchments. The mainstem is analogous to the trunk of the tree and the tributaries its branches.

In terms of data availability, there exist a number of monitoring points at which both flow and water quality are monitored. Such points exist for both the mainstem as well as at the outlet (branch to trunk) points of key quaternaries. This spatiality of data availability, coupled with data for wastewater treatment works (WWTW) point source loads, supports a reasonable level of load disaggregation. Whether or not the data quality will support the use of TMDLs at a management (legal compliance) level is less clear and is discussed elsewhere in this report.

The Berg River provides an example of an important major river system that supports a considerable socio-economic development area. The availability of data for this CS probably typifies that for other, similarly important, river systems in South Africa. Most other river systems will be monitored at a lesser level, if at all. However, as the ‘working rivers’ such as the Berg will be the most impacted by anthropogenic development, such systems are likely to be those requiring a high level of spatial management definition.

Export Coefficient-Dependent Method

This method applies to catchments with few or no flow and/or water quality monitoring and where there is thus a high dependency on nutrient runoff modelling. In these cases it is necessary to model pollutant runoff, based on export coefficients and compare the predicted loading with that derived from observed data, i.e. at the first available monitoring point in the DWA WMS. At the present time use this approach, for the purpose of implementing any form of TMDL management, would be prone to a low confidence level and would probably not provide a legally-enforceable directive.

The Theewaterskloof CS provides an example of a catchment in which modelling of runoff and pollutants will be required. Additionally, the first “Tree and Branch” location in this CS is the Theewaterskloof Dam, i.e. a lentic as opposed to a lotic environment and hence provides an additionally set of modelling constraints posed by the behaviour of pollutants in reservoirs.

It is probable that, should TMDLs be required in poorly-monitored catchments, that ad hoc monitoring sites will need to be installed and monitored for a requisite period. It is noted that some of these catchments are supported by an historical database derived from a monitoring station at which monitoring has been discontinued. Although not examined in detail it is surmised that the greater number of TMDL-candidate rivers will fall into the Tree and Branch data support category.

The use of the Export Coefficient Method requires the availability of rainfall and terrain (elevation) data. While such information is readily available as model “plug-ins” for TMDL assessments in the USA, no such database of information yet exists in South Africa. On an *ad hoc* basis, however, it is arguable that such data could be derived in relatively short time. Negating the use of export coefficients have been findings that reveal the lack of a relationship between stormflows and export (e.g. Coser, 1989).

A final and perhaps crucial limitation of the Export Coefficient Method is that, to-date, there have been no (South African) studies that have provided a robust set of export coefficients per area and/or landuse type, for example to the USA’s MANAGE database. This would limit the implementation of TMDLs to the requirement for, for example, specific Best Management Practices applied across a whole catchment, rather than to specific polluters. It should not, however, prove difficult to derive landuse-linked export coefficients for South Africa (see hereunder).

Method Combinations

The Berg River CS provides an opportunity to apply the Export Coefficient Method in a catchment or sub-catchment that possesses a Tree and Branch dataset. As such the opportunity to test the efficacy of known export coefficients or to potentially derive export coefficients, presents itself, albeit at a relatively superficial level (cf the MANAGE database type of info). For this assessment, both methods require the incorporation of a model for determining the nutrient load-response in a reservoir, i.e. the point at which the TMDL rule will be set. A simple load-response model has been chosen as the time and data requirements necessary to establish complex models, such as QUAL2E, are beyond the scope of this project.

3.2 MODEL SELECTION

For the purposes of load determination (i.e. the product of flow and concentration of a specific pollutant), water quality monitoring in South African rivers is typified by continuous flow recording (usually as a daily average expressed in cumecs) and considerably less-frequent collection of grab samples for water quality analysis. The latter is at best available at 14-day intervals, in many cases monthly.

This limited matching of flow and concentration presents a very real challenge to the efficient and enforceable application of TMDLs in South Africa. In order to do so, models must be used to 'infill' the missing concentration data, based on model calibration derived from those days when samples were collected. For this to be robust there is a requirement for sample data to match the full spectrum of flow conditions and over period long-enough to provide same (if fortnightly samples are collected then only 24 samples are available per annum, as opposed to 365 flow days). This requires five to ten years of data availability to produce an acceptable calibration set.

Tool selection

As this project entails a fact-finding test of the TMDL approach (excluding the administrative and public process component), the selection of model "tools" was specifically limited to those already in existence and available 'freeware'. This was achieved with one exception. The creation of support software, however, was included in order to provide for data handling (extraction of data from DWA databases and conversion to formats required for entry into, for example, the USA-derived loading models), as well as the creation of bulk data handling protocols to enable single data processing runs for multiple sites).

Model selection criteria

The criteria for selecting models were based on those used for the Central Oahu Watershed study (2008):

- Hydrologic modelling capabilities
- Continuous event modelling (i.e. monthly results averaged over an event or season)
- Mixed land use modelling
- Ability to simulate nutrient pollution
- BMP evaluation
- Linkage to GIS (freeware)
- Graphical user interface for pre-processing (e.g. Windows based input data editors)
- Model availability (public domain vs. proprietary, software cost, etc.)
- Requirements for user modelling experience

Model selection process

The following sequence was used to select the models to be used:

1. Identify model selection criteria
2. Identify models suitable for the scope of this feasibility study
3. Identify shortlist of models
4. Develop models for application (Deliverable 4)
5. Evaluate models and output(s)

Use of models

The use of models for TMDL determinations is a necessary evil in all cases except where a minimal number of clearly defined point sources (e.g. WWTW effluents) constitute the bulk load. Arguably WWTW effluents should be required to meet zero-load limits for certain pollutants, such as phosphorus. Such a level of control would, in many cases, obviate the need for phosphorus-based TMDLs.

The use of models is and will remain a fundamental component of the TMDL protocol. As noted by De Pinto et al. (undated), "(as) …*mathematical modelling of aquatic systems is not an exact science, it is essential that these steps be fully transparent to all TMDL* *stakeholders through comprehensive documentation of the entire process, including specification of all inputs and assumptions*".

The legally-enforceable use of models, however, requires the stringent evaluation of simulated data compared with that observed in practice (e.g. Moriasi et al. 2007). The use of TMDLs as management tools requires that the methods are both robust and transparent to all concern. In the absence of well-developed databases, the use of predicted data to enforce pollutant disposal remains eminently challengeable. By implication, the process whereby model results are accepted, rejected or qualified needs to precede model evaluation. This feasibility study makes use of existing models and assumes that model evaluation has been considered and addressed.

The use of measured data is prone to uncertainties. As noted by Moriasi et al. (ibid), "In most watershed modeling projects, model output is compared to corresponding measured data with the assumption that all error variance is contained within the predicted values and that observed values are error free. In discussions of model evaluation statistics it is recognized that measured data are <u>not</u> error free, but measurement error is not considered in the recommendations perhaps because of the relative lack of data on measurement uncertainty. However, uncertainty estimates for measured streamflow and water quality data have recently become available (Harmel et al. 2006) and should be considered when calibrating, validating, and evaluating watershed models because of differences in inherent uncertainty between measured flow, sediment, and nutrient data".

As noted by Harmel et al. (*ibid*), "the issue of uncertainty is particularly important in water quality modeling because models are increasingly used to guide decisions regarding water resource policy, management, and regulation".

This project notes the requirement for data to be subjected to uncertainty analysis. This is, however, not a requirement for this feasibility study.

Data examination

This project has selected to trial the TMDL approach based on Total Phosphorus (TP). For the initial purposes of model selection, the dataset derived from the Berg River Monitoring Point 101939 (Hermon, see **Figure 1**) was used. Note the lack of correlation between flow and TP concentration (i.e. very few samples collected during high flow events).

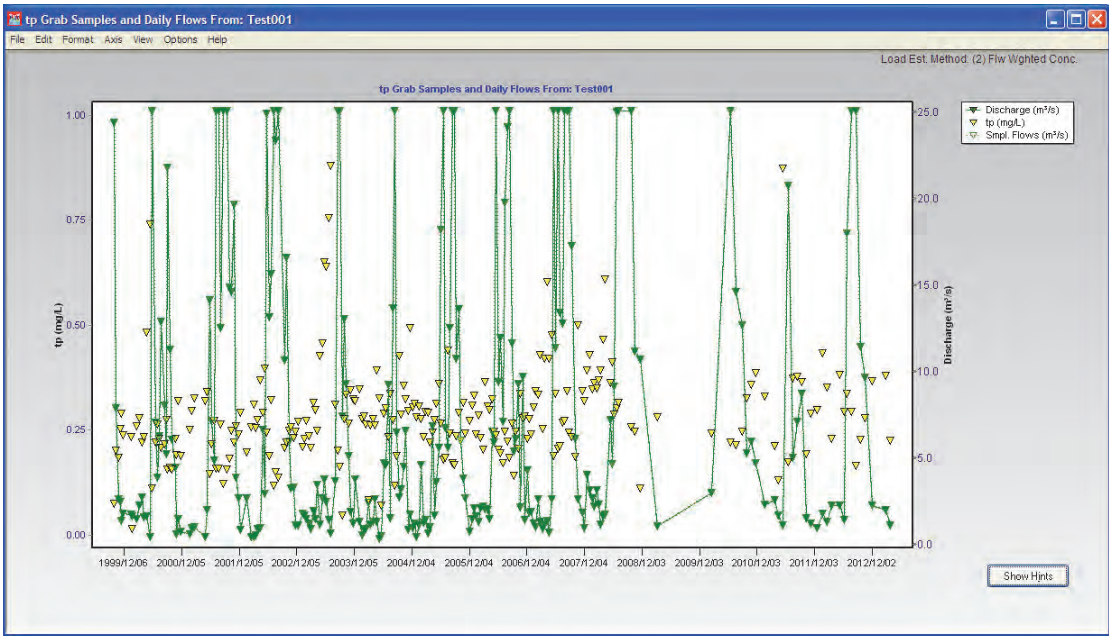

Figure 3-1: Overlay of discharge and TP at Hermon (101939)

These data revealed that, as expected, the concentration of TP (or ortho-P, see **Figures 3-2 & 3-5**) was independent of flow (e.g. Sigleo and Frick, undated; Ward et al. 2010). Secondly, and less expected, was that the collection of water quality samples was essentially limited to the lower band of flows, with almost no samples collected during high flow conditions. There were, however, enough matched occasions to support model calibration but not without limiting the value of the output. It must be borne in mind, however, that the fact that TP concentration appears to be largely independent of flow offsets the absence of samples collected during high flow conditions. This conflicts with the findings made by Bath (1989), discussed further hereunder.

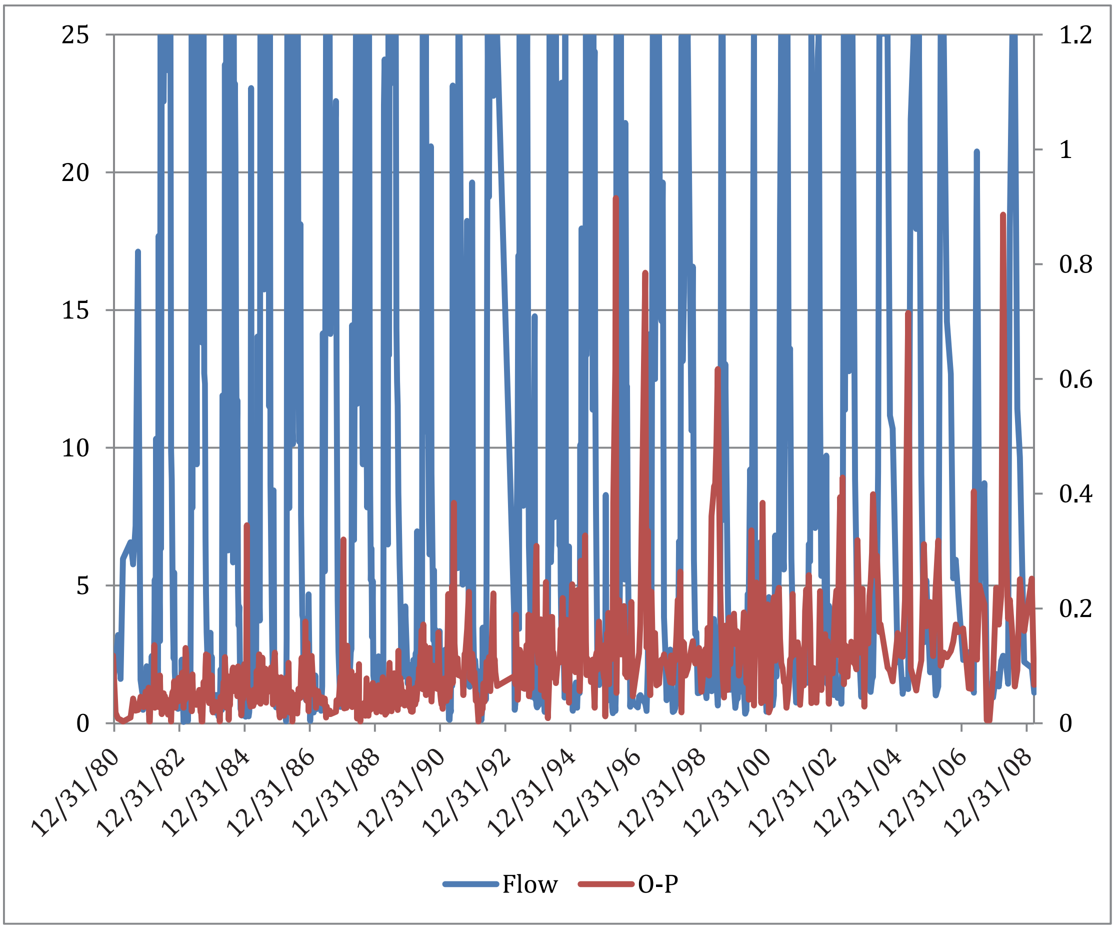

Figure 3-2: Graph showing flow vsortho-P at Hermon (101939)

The common lack of water quality and corresponding flow data is primarily due to issues of travel time, cost and laboratory throughput ability – but also involves rainfall variability, adverse weather conditions and equipment limitations.

Derivation of TP from Orthophosphate (O-P)

The determination of TP in the DWA WMS is a relatively-recent addition to the long-standing determination of O-P. TP analyses were introduced a decade or so ago, largely in response to the insistence for this by reservoir limnologists modelling eutrophication response based on TP data. As a result, relatively few monitoring stations have both TP and O-P data, whereas they all have O-P.

In broad terms it is possible to derive TP concentrations from O-P data, provided that the source types are known. For example, the TP content of a WWTW effluent will be dominated by the O-P form, whereas that in an agricultural context would be TP in a particulate-bound form. This situation is further complicated by large contributions of runoff from informal settlements – which combine sources from informal wastewater disposal to street abattoirs.

A sub-task of this project has entailed the preliminary derivation of TP:O-P relationships where data for both P-forms exist and then to use these to derive TP for other stations in the same type of river reach (i.e. same type of likely pollutant source) (see **Figure 3-3**).

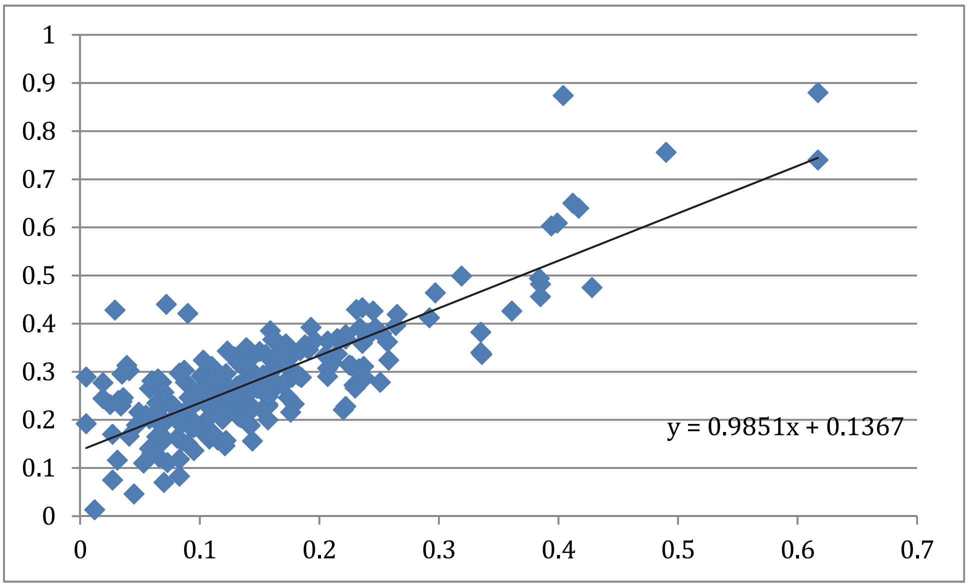

Figure 3-3: Relationship between TP and ortho-P at Hermon (101939)

3.3 MODELS & TOOLS SELECTED

GIS

<u>QGIS™</u>

GIS forms a fundamental point of departure for the establishment of TMDLs and is the most effective means of compiling and overlaying all available information. This project initially established the GIS layers using the ESRI software *ArcGIS* and then ported the output into the freeware and easy to use *QGIS* program

<u>Didger™</u>

Extraction and ortho-rectification of catchments, sub-catchments and landuse types, as well as terrain slope determinations for runoff analyses, for inclusion in the GIS analysis, is an important component of the Export Coefficient method. Until recently this required the contracting of GIS service providers or surveyors to undertake this. The recent availability of the *Didger* product (Golden Software) now allows for the easy extraction of map or aerial photographs, including from GoogleEarth and their ortho-rectification for direct use in GIS. While it is noted that ortho-rectification can be accomplished in QGIS, the method was found to be cumbersome and prone to errors and distortions, issues that are not present in *Didger*.

Export Coefficients

<u>SANED</u>

The South African Nutrient Export Coefficient Database (SANED) was derived in 2007 for the DWA (Enongene and Rossouw 2007). The database is available in a GIS format compiled with a viewer. The database is simply a GIS rendition of a limited number of locations in South Africa where export coefficients have previously been determined. Its use for runoff Q-C modelling is thus extremely limited. Until such time as South Africa develops a comprehensive suite of export coefficients that embody considerations of geology, soil types, terrain and gradient, the enforcement of TMDLs will be prone to challenge.

<u>MANAGE</u>

The "Measured Annual Nutrient Loads from Agricultural Environments" (=MANAGE) database contains data from the bulk of peer-reviewed N and P export studies conducted on agricultural lands in the USA, under natural rainfall conditions (Harmel et al. 2006, 2008). While not applicable for use in South Africa, the database provides a clear example of the type of accessible database resource that would be required locally. MANAGE is currently available in form of an MSAccess database.

3.4 MODELS SELECTED FOR USE AND EVALUATION

In this section use of the term 'complexity' refers to the input data requirements of the individual models.

Low complexity models

<u>FLUX32</u>

FLUX is a Windows-based interactive program for estimating nutrient loads, or loads of other components, based on data gathered from a monitoring station. While the tool was originally developed for determining eutrophication loads for lakes and reservoirs (Walker, year) it is ideally suited for the determination of TMDL-related loads. The data requirements are (i) grab sample concentrations of the parameter for which a load is to be determined; (ii) corresponding flow measurements for each grab sample and (iii) a complete flow record for the period being evaluated.

The program is calibrated using a matched flow and concentration dataset, where after load estimates are derived using a sample file that only contains flow data. The program is easy to use and includes a variety of load determination algorithms, as well as an option to determine TMDLs, this option requiring watershed and runoff data.

An example of the outputs from FLUX32 is provided in **Figures 3-4 - 3-7**.

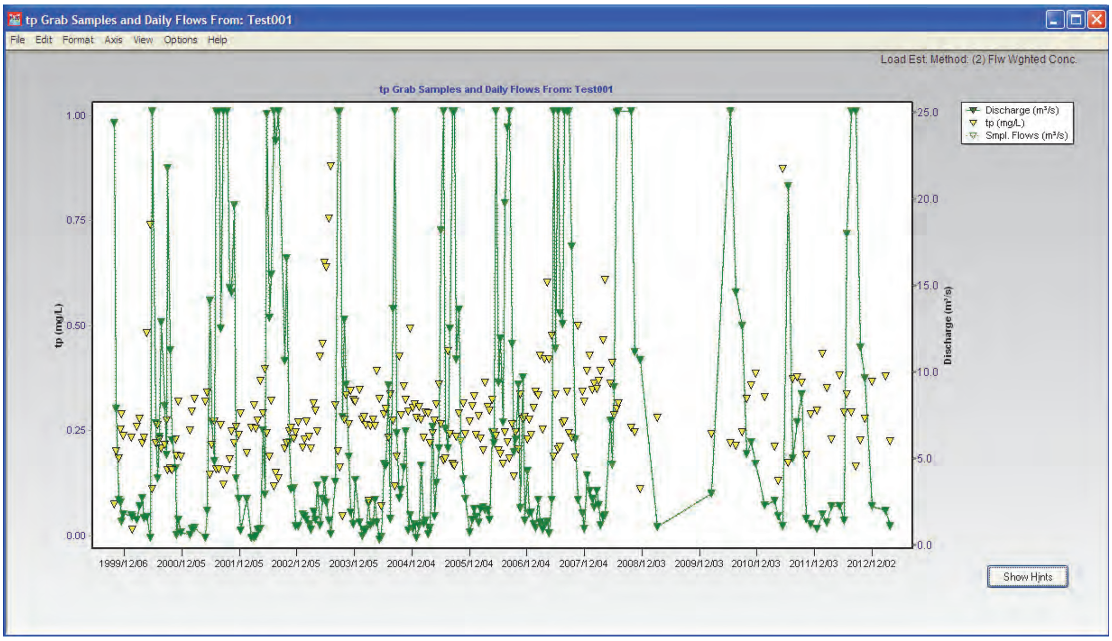

Figure 3-4: Example of flow and sampling at Hermon

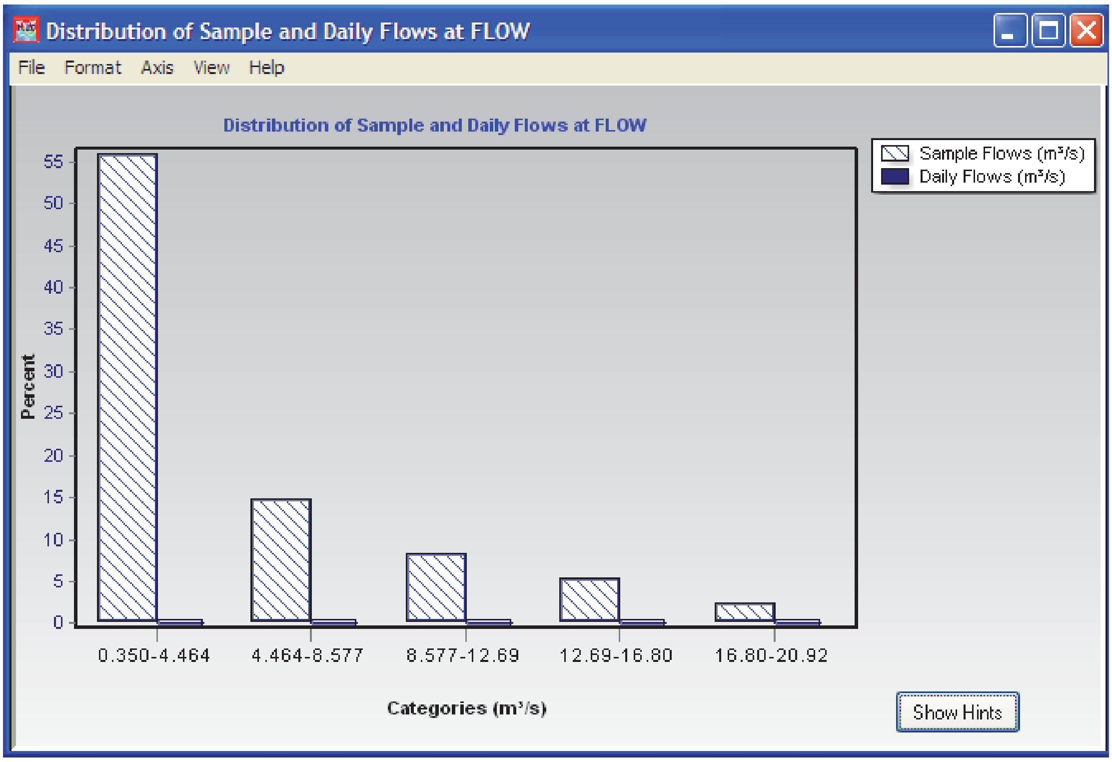

Figure 3-5: Distribution of samples vs flow on day of sampling

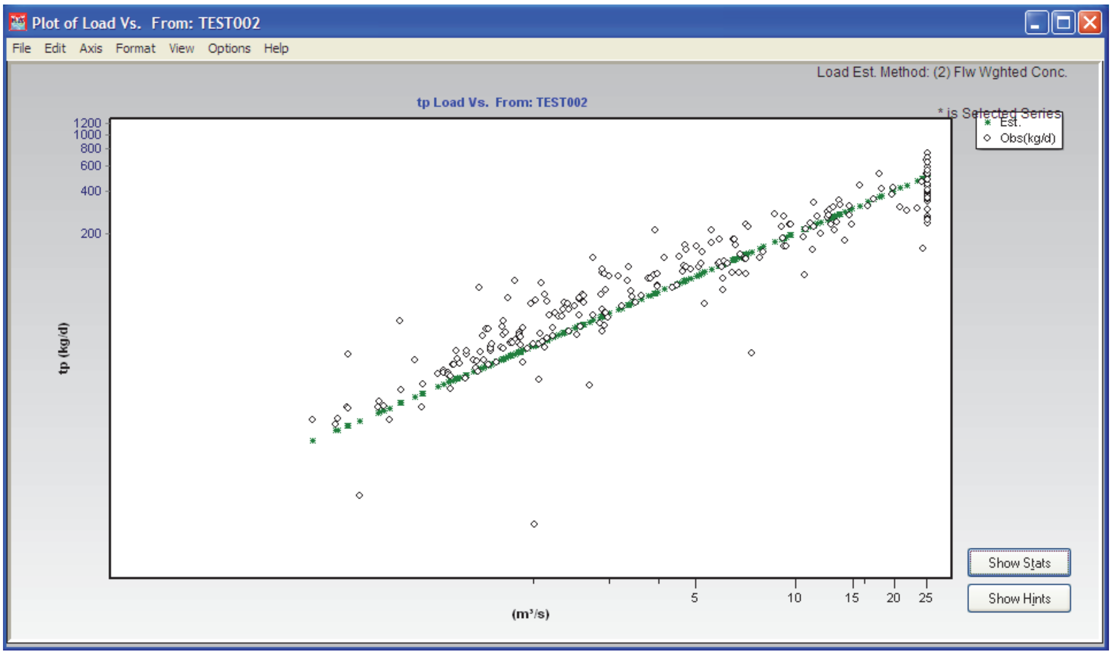

Figure 3-6: Relationship between flow and TP load at Hermon.

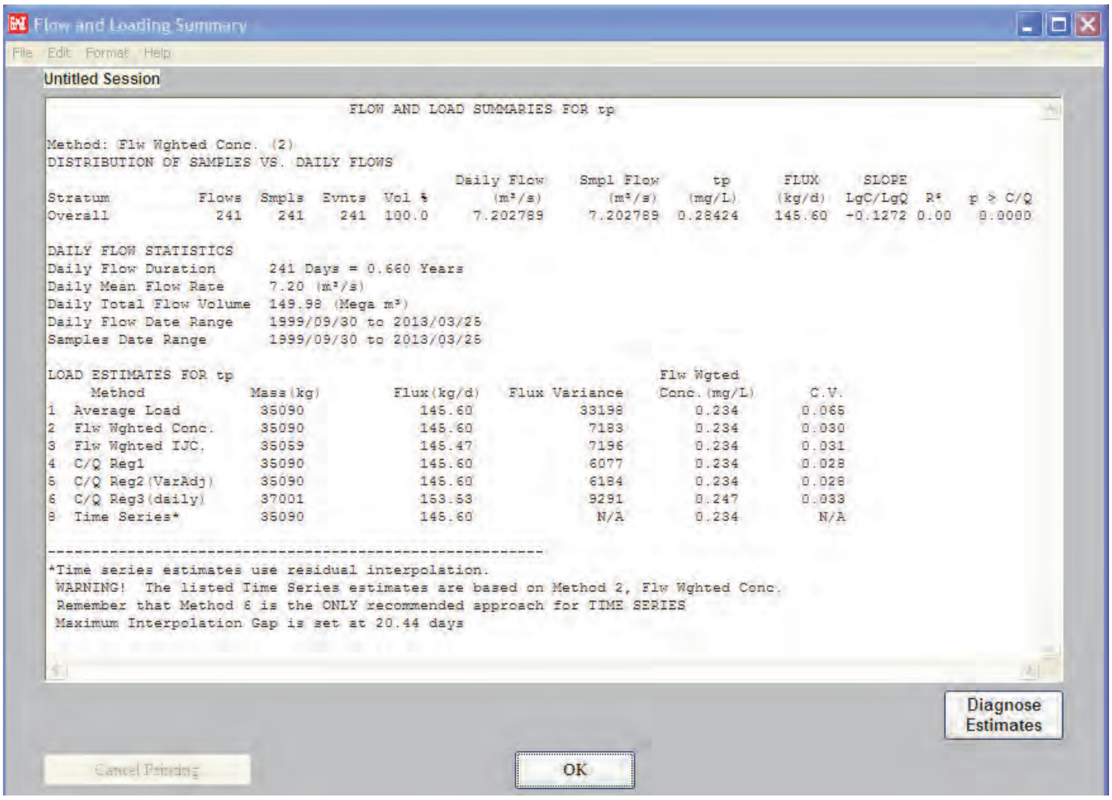

Figure 3-7: Example of load calculations from the FLUX software.

A program enabling the direct processing of DWA-WMS data to FLUX32 was purpose-compiled for this project (see WQFLOW, below).

LOADEST

LOADEST is similar in concept to FLUX32 but is a command Line program that is not equipped with a GUI. It is a FORTRAN-based program designed for estimating nutrient loads in rivers and streams. The software provides, in addition to automated model selection, three alternate load estimation routines and augments FLUX32.

The preparation of the various input files is somewhat cumbersome and time-consuming (see **Figure 3-8**). In order to offset this limitation a program enabling the direct processing of DWA-WMS data to LOADEST, as well as to offset the need to enter information via a Command Line sequence, was purpose-compiled for this project (see WQFLOW, below). This program automatically prepares the input files, runs the routines and produces the output files.

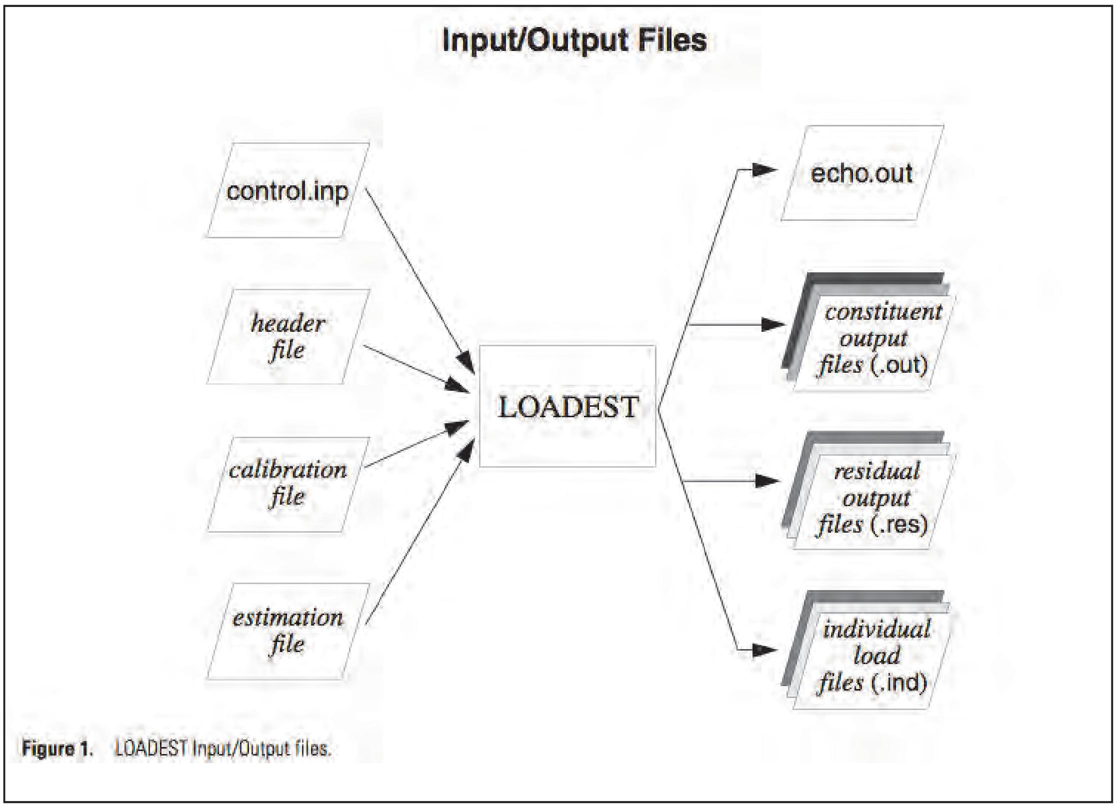

Figure 3-8: Input and output files for the LOADEST application.

Malan *et al.*

A descriptive protocol for flow-concentration modelling for rivers, formulated as an aide for the Ecological Reserve protocols, has previously been derived (Malan et al. 2003). This approach offers no automated routines and does not offer anything that is not already embodied in the older FLUX and LOADEST programs.

NEAP

NEAP (Nutrient Enrichment Assessment Protocol) is a coarse-level, watershed-scale nutrient loading and lake response model specifically produced for use in South Africa (Harding, in Rossouw et al. 2008). The model provides information concerning the appropriate mix of point source discharges, land use, and land management controls that results in acceptable lake water quality. NEAP is intended for predicting flushing-corrected, annual lake-wide average conditions for the growing seasons as a function of annual loadings. NEAP, with its simple data input requirements, forms an ideal tool for assessing management needs and determining the impact of nutrient attenuation via BMPs or other measures.

NEAP was developed as a spreadsheet-based model as part of a WRC project addressing nutrient management at the catchment level (reference). The tool was made available as a freely-available internet product and was hosted and widely used for a period of five years following development. The service has since been discontinued as the WRC did not extend the project into a further phase that included model maintenance and the inclusion of additional modules for erosion and sedimentation calculations.

Purpose designed data processing program

WQFLOW

The program *WQFlow* was specifically written for this project to enable the simple and rapid preparation of input files use with FLUX32 and LOADEST. The program extracts the required data from the DWA hydrology and water quality files, prepares the input files and, in the case of LOADEST, runs the routine and produces the output files. The use of WQFlow reduces the amount of time required to utilize the load estimators by approximately 90%.

The output of both FLUX and LOADEST have been tested against a manually-determined load using DWA. Both models produced outputs identical to the manual calibration.

Moderate complexity models

N-SPECT

N-SPECT is a geographic information system (GIS)-based, spatially distributed screening tool that models basic hydrologic processes, including overland flow, erosion, and nonpoint-source pollution for watersheds (see **Figure 3-9**). The model operates on annual and event time scales and includes options for user-specified land use and land management scenarios.

The Environmental Systems Research Institute's (ESRI) ArcGIS software and the Spatial Analyst extension are required to run N-SPECT, which was designed to be simple so that average desktop machines could run the model quickly. N-SPECT takes advantage of ESRI's geodatabase architecture to store tabular data necessary to run the model. This increases the transparency of the tool and allows users to easily view and manipulate information, such as pollutant coefficients, runoff curve numbers, water quality standards, and file path names.

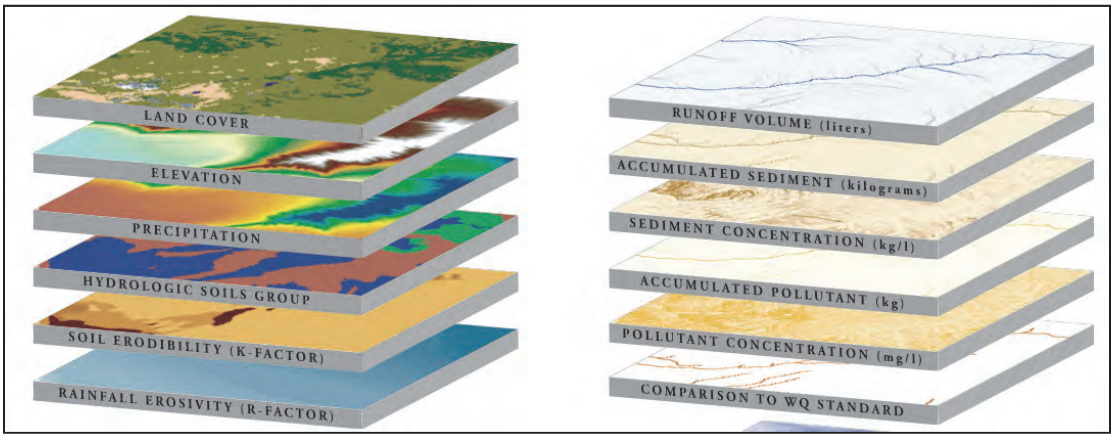

Figure 3-9: Input (left) and output (right) layers for the NSPECT software.

The NSPECT approach embodies some aspects that have potential for application in South Africa in future, should further development of TMDL support systems be indicated. Although it is categorized as a low-complexity model, it currently requires the use of "need to purchase" software, viz. ESRI ArcGIS.

GWLF

The GWLF model is the core or "engine" of BasinSim 1.0 (see following). In BasinSim 1.0, the GWLF model simulates the hydrologic cycle in a watershed, predicting streamflow based on precipitation, evapotranspiration, land uses and soil characteristics. The general structure of the GWLF model is shown in **Figure 3-10**. Loading functions specific for the watershed are used along with the hydrologic cycle to predict nutrient loads from surface runoff, groundwater, point sources, and septic systems. In addition the simulation provides monthly streamflow, soil erosion, and sediment yield.

The GWLF model simulates monthly and annual streamflow, sediment transport, and associated nitrogen and phosphorus fluxes, and was designed for use in mixed-use watersheds (urban, multiple agricultural land uses and forested land use).

Input data for the GWLF model can be obtained through US databases maintained by local, state and federal agencies such as the National Climatic Data Center, Soil Conservation Service, and various planning districts (**Table 3-1**). It is likely that the model can be used with ad hoc information prepared for a specific catchment.

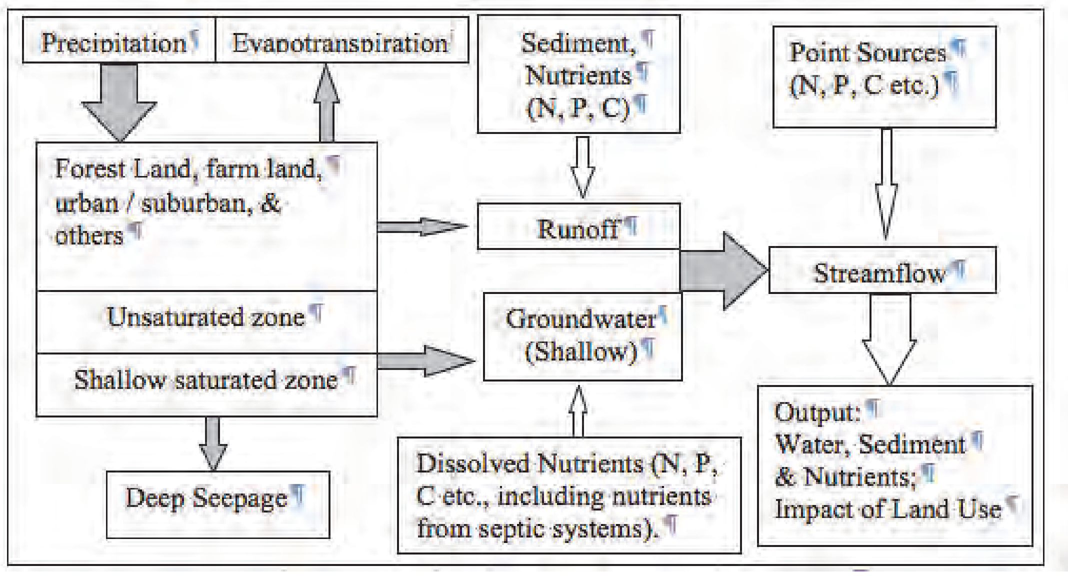

Figure 3-10: Structure of the GWLF model

Table 3-1: Summarized data requirements for the GWLF model

DATABASE	**INFORMATION SOURCES**
Climate (Daily Precipitation & Temperature)	National climatic data center
Land Use / Land Cover	USGS, EPA regional land use map, Landsat imagery, & federal statistics
Elevation and Slope	USGS digital elevation model
Soils Parameters	Local soil maps, SCS STATSGO & MUIR databases NRCS National Resources Inventory (NRI) database
Hydrography	USGS hydrography map
Nutrient Concentration in Runoff and Soils	Literature and Haith et al. (1992)
Water Discharge & Water Quality Data	USGS water data & EPA STORET database
Population	U. S. Bureau of Census
Sewer System or Septic Tanks	U. S. Bureau of Census & local health departments
Point Sources	EPA, State & local statistics

It should be evident from the foregoing that the use of the GWLF approach, although valuable for TMDL determinations, will not be possible until the required, supporting databases of local information have been developed.

<u>BasinSim</u>

BasinSim 1.0 is a Windows-platform desktop simulation system that predicts sediment and nutrient loads for small to mid-sized watersheds. The simulation system is based on the Generalized Watershed Loading Functions (GWLF, see below), a tested watershed model (Haith and Shoemaker 1987, Haith et al. 1992). BasinSim 1.0 integrates an easy-to-use graphic Windows interface, extensive databases (land uses, population, soils, water

discharge, water quality, climate, point nutrient sources, etc.), and the GWLF model (with modifications) into a single software package. It was designed to enable resource managers to visualize watershed characteristics, retrieve historic data (at the county and sub-watershed levels), manipulate land use patterns, and simulate nutrient (N, P, and organic C) and sediment loadings under various scenarios.

The use of BaisinSim is substantially-constrained by the need for regionally-specific databases of information on which the model needs to draw. These information sources do not exist for South Africa. While elements of these could be formulated for case specific use in South Africa, this would add significantly to the time and cost input requirements for generating a TMDL, as well as limiting the confidence level of the results.

<u>EutroMod</u>

EUTROMOD is a watershed-scale nutrient loading and lake response model. The model provides information concerning the appropriate mix of point source discharges, land use, and land management controls that results in acceptable lake water quality. EUTROMOD is intended for predicting lake-wide average conditions for the growing seasons as a function of annual loadings. Access to use of the model is limited and was not assessed further in this project.

High complexity models

<u>NANI-NAPI</u>

NANI (Net Anthropogenic Nitrogen Inputs), an 'accounting system' first introduced by Howarth et al. (1996, Cornell University), estimates the human-induced nitrogen inputs to a watershed and have been shown to be a good predictor of riverine nitrogen export at a large scale, multi-year average basis. NANI have been calculated as the sum of four major components: atmospheric N deposition, fertilizer N application, agricultural N fixation, and net food and feed imports, which in turn are composed of crop and animal N production (negative fluxes removing N from watersheds) and animal and human N consumption (positive fluxes adding N to watersheds) (see **Figure 3-11**). Assuming approximate steady-state behaviour, riverine N export is a fixed proportion of net nitrogen inputs. A relatively complex suite of model tools is required for effective execution of the NANI approach (see **Figure 3-12**).

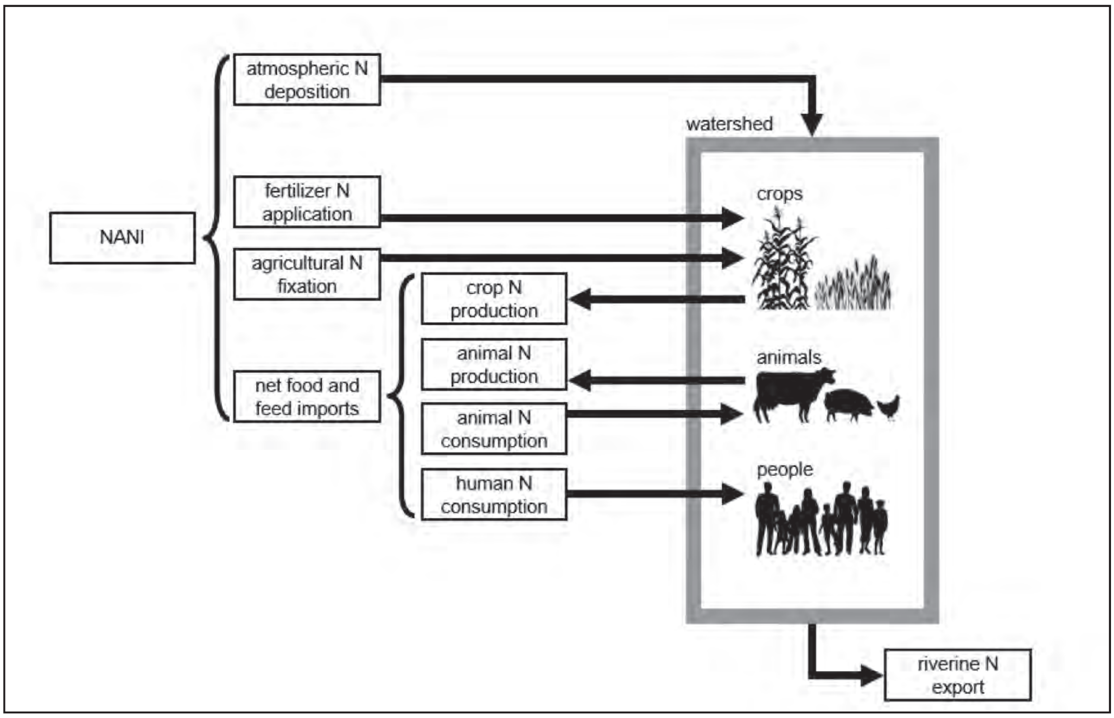

Figure 3-11: Example of NANI accounting for N loading

Similar calculations can be made for phosphorus (P) inputs, though because atmospheric deposition of P is usually considered negligible and there is no analog in P for atmospheric fixation, the calculation of Net Anthropogenic Phosphorus Inputs (NAPI) reduces to accounting for P fertilizer and P in net food/feed terms. There has, however, been minimal use of the NAPI alternative.

The NANI/NAPI approach embodies a major need for model-specific GIS resources, as well as being a licensed application, rendering the application inapplicable in South Africa at the present time. The useable datasets are currently limited to the USA, although there has been mention of the development of global datasets for nitrogen. It is considered unlikely that development of any support systems relevant to use in South Africa will be forthcoming in the mid- to long term.

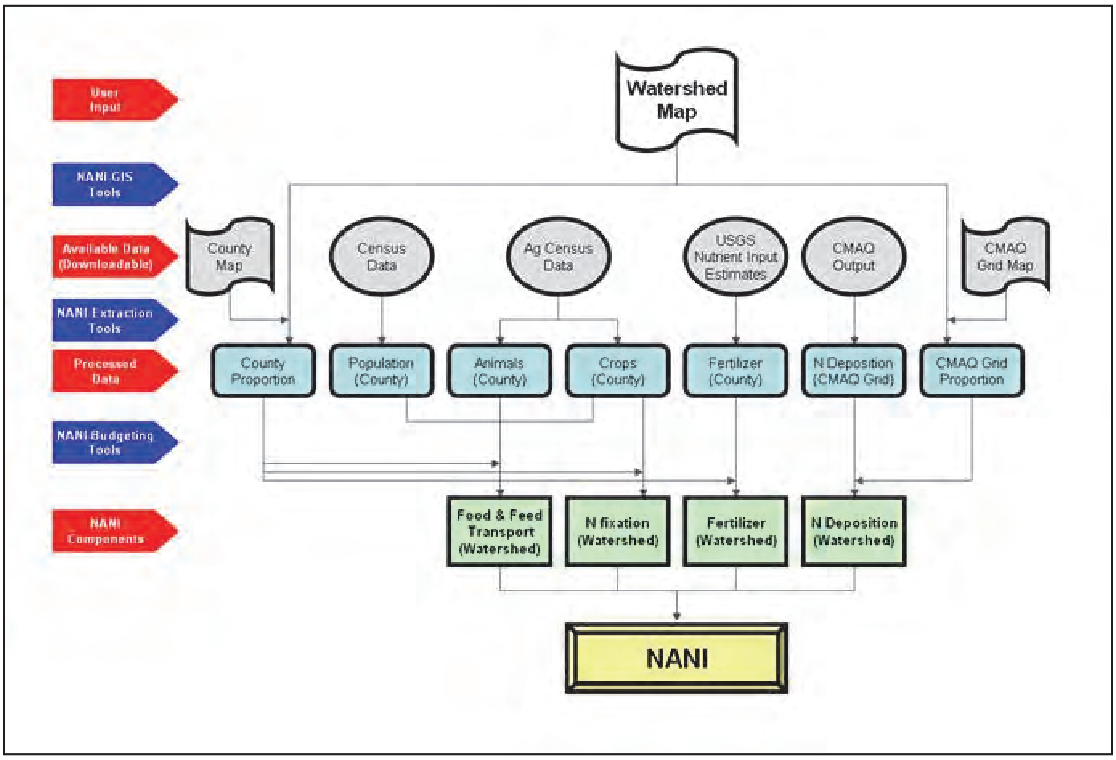

Figure 3-12: Schematic indicating the complexity and data requirements of the NANI model.

<u>ReNuMa</u>

ReNuMa (Regional Nutrient Management, Hong and Swaney, 2007) is based on a simple, large-catchment transport model (GWLF; see above and **Figure 3-13**) as well as empirical relationships between nitrogen inputs to watersheds and corresponding concentrations in outflows. ReNuMa is based on two lines of earlier work: GWLF (Generalized Watershed Loading Functions; Haith and Shoemaker 1987), which is a lumped-parameter, watershed-scale hydrology, sediment, and nutrient transport model, and NANI (Net Anthropogenic Nitrogen Inputs), which is an accounting methodology for nitrogen inputs to watersheds.

The tool runs in Excel (with Solver add-in) and uses simple runoff, sediment and groundwater relationships based in part on monthly mass-balances. Validation studies conducted on 16 NE US watersheds indicate that the model generally reproduces seasonal and annual patterns of discharge and N flux across watersheds. Evaluation of other nutrient fluxes is ongoing. Although more accurate results are perhaps obtainable from more detailed chemical simulation models, such models typically have substantially greater data and computational requirements.

As with its parent model, the details of nutrient chemistry and farm field operations are not modelled explicitly in ReNuMa at present, so the model cannot be used to estimate the detailed responses to some management practices (e.g. fertilizer management or urban storm water storage and treatment). Although the urban runoff component is based on well-known relationships that have been used previously in such models as STORM and SWMM, performance in urbanized watersheds is uncertain.

The model has a distinct focus for nitrogen flux determinations and requires both daily weather data and input data for groundwater and soil nutrients, information that is unlikely to be readily available for South African application. There are, however, components of the model that may be of merit for use in hydrology and stream load determinations. For this project ReNuMa will be evaluated against calibrated output from the FLUX and LOADEST applications.

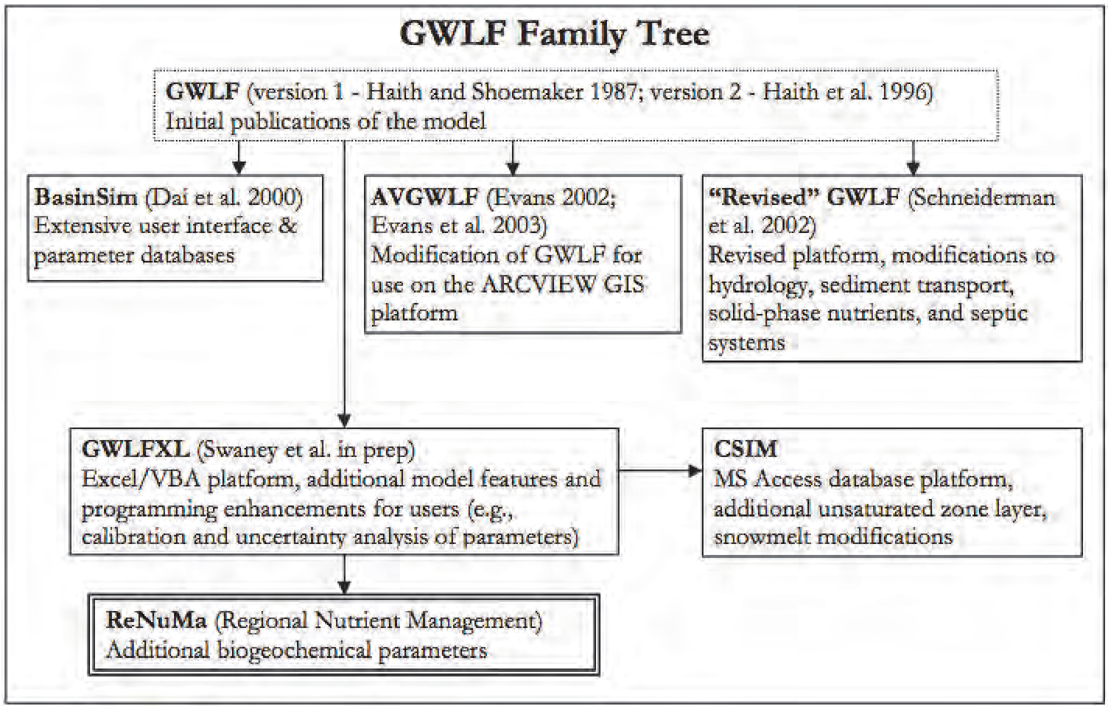

Figure 3-13: Genealogy of the GWLF family of models

<u>WARMF</u>

WARMF (Watershed Analysis Risk Management Framework) is a high complexity, physically-based simulation model. Similar to the other non-grid based pilot models, the WARMF model framework is based on linkages of sub-basins and streams.

WARMF does not include functions for performing sub-basin and stream delineations but it does have functions for importing delineations with attributes processed by the ArcSWAT tool or BASINS.

INCA

Details of the INCA (Integrated Catchments) models for nitrogen (INCA-N) and phosphorus (INCA-P) were only identified at a late stage of development of this project. Although the nitrogen model is considerably more developed (the project commenced in 1995), both distributions embody potential for development for local use, not least because of the extensive and collaborative model design backgrounds. The data input requirements are substantial, as summarized below from the INCA-N manual:

"The input fluxes which the INCA-N takes into account are: atmospheric deposition of ammonium and nitrate (wet and dry), ammonium and nitrate fertiliser applications; mineralisation of organic matter (to form NH_4) and nitrification (to form NO_3); and nitrogen fixation. From these are subtracted various output fluxes (plant uptake; immobilisation and denitrification) before the amount available for stream output is calculated. These inputs and outputs are differentiated by landscape type and varied according to environmental conditions (soil moisture, temperature). The model accounts for stocks of ammonium and nitrate in the soil and ground water pools, and in the stream reaches. The model also simulates the flow of water through the plant/soil system from different land use types to deliver the N load to the river system, which is then routed downstream after accounting for direct effluent discharges, and in-stream nitrification and de-nitrification".

INCA-N is designed to minimise data requirements. To this end, the model may be successfully run using surprisingly little input data:

- **Hydrological and meteorological data** – daily air temperature, hydrologically effective rainfall, soil moisture deficit and actual precipitation.
- **Reach structure** – reach length, velocity/flow relationship parameters
- **Sub-catchments** – area, land use proportions, base flow index

For successful calibration, however, good quality observed data and physical catchment descriptors are necessary:

- **Observed data** – flow, nitrate-N and ammonium-N
- **Effluent/abstraction data** – either annual averages or daily time series
- **Fertiliser inputs** – either annual averages or daily time series
- **Crop growth timings** – start dates and periods
- **Deposition inputs** – either annual averages or daily time series

In the UK, it is anticipated that these data should be readily available from government agencies, regulatory bodies and routine field experiments. Similar information may be available in South Africa but would need to be collated and prepared for use with the model.

The phosphorus version of the model, INCA-P, is a dynamic, mass-balance model with fine temporal resolution but has quite demanding input data requirements including TP and ortho-P streamwater concentrations, landuse, daily precipitation, discharge, flow velocity, soil moisture, baseflow index, fertilizer practices, application/timing/growing season) (Wade et al. 2002) but, of all the complex models assessed, holds the greatest potential for local development (see Figures 3-16 to 3-.

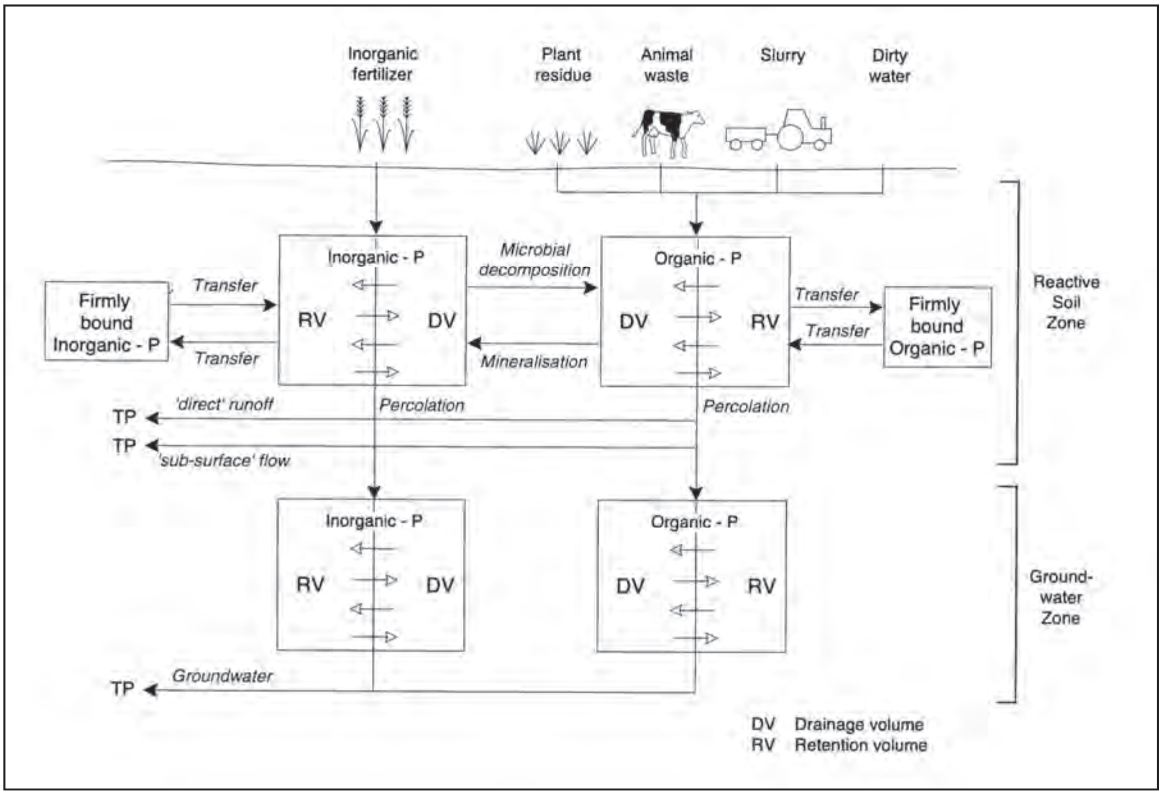

Figure 3-14: Land phase component cell of the INCA-P model (Wade et al. 2002)

The INCA-P model is ideally suited to modelling the various processes that affect P transport in rivers and streams (see Figures 3-14 to 3-17). Adaptation to include an irrigation abstraction module would be necessary. It has been successfully used to model eutrophication in the River Thames and to associate costs with the degree of nutrient-related impairment (see Figure 3-17) (Whitehead et al. 2013).

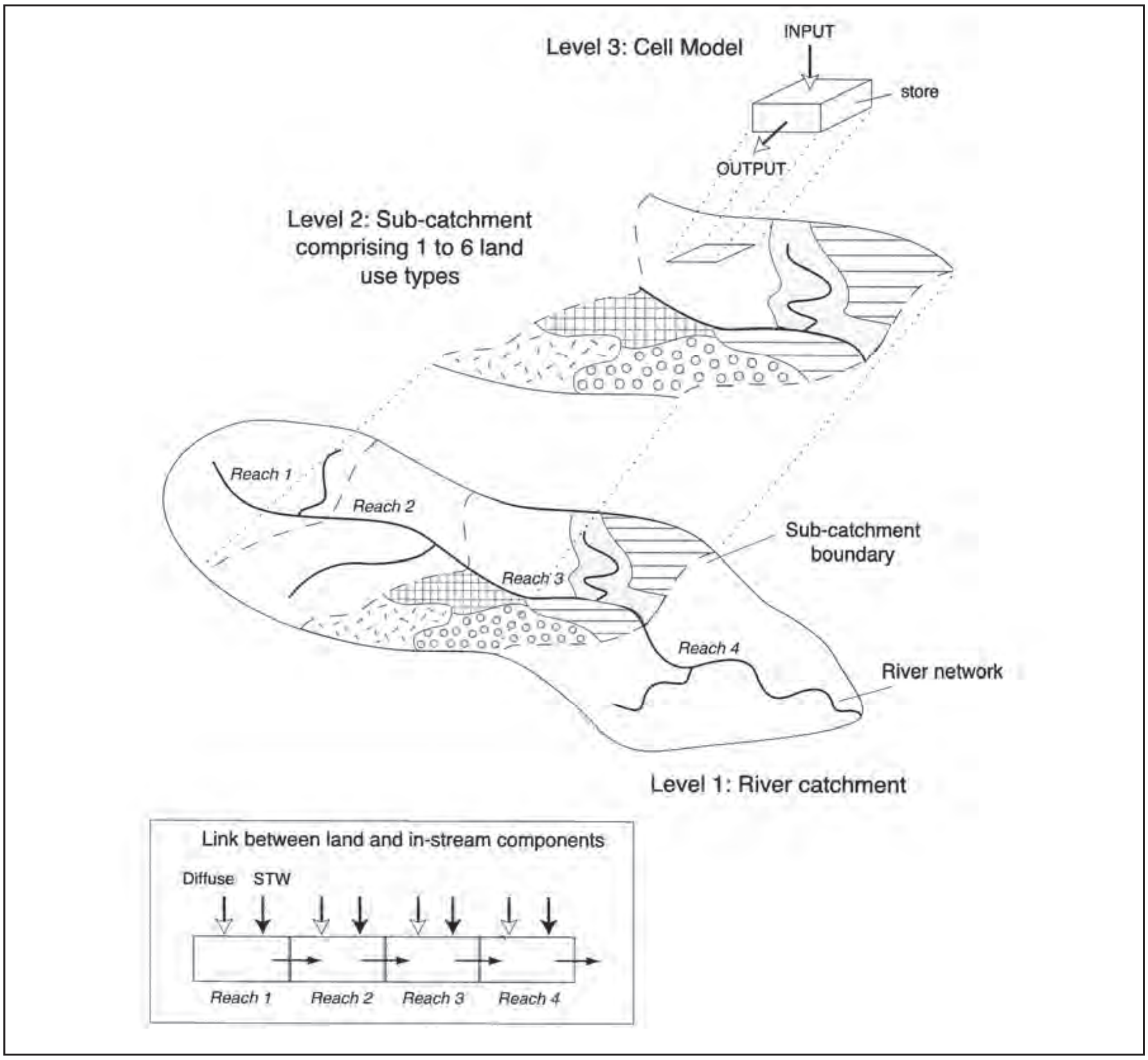

Figure 3-15: INCA-P land phase component model structure

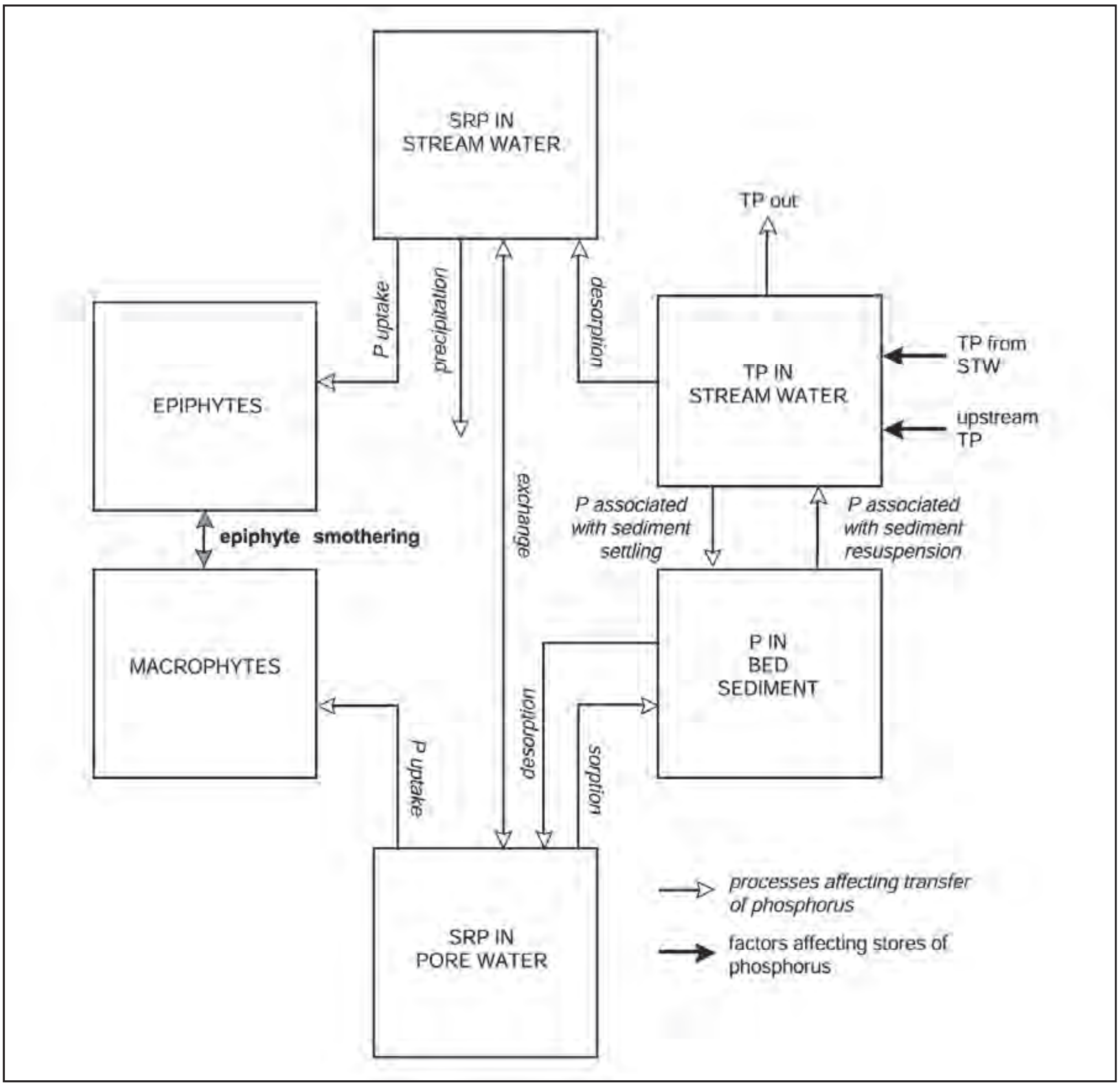

Figure 3-16: INCA-P stream model components

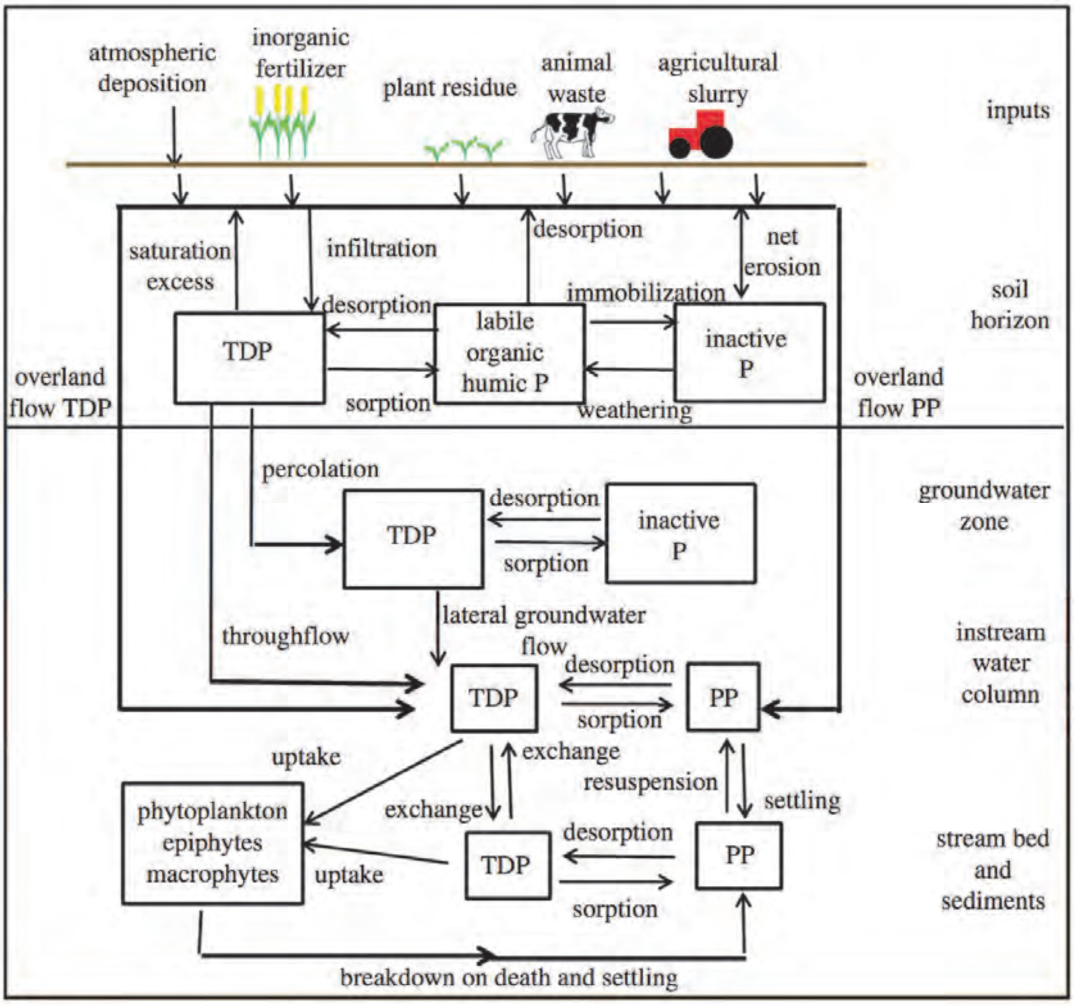

Figure 3-17: INCA-P combined model components

Model evaluation matrix

Table 2 shows the summarized model selection process.

Table 3-2: Model selection matrix

Model	Model capabilities										
Criteria >> (Model capabilities: 1 = Low, 2 = Moderate, 3 = High, 4 = None)	Hydrologic modelling	Event modelling	Mixed landuse modelling	Simulate nutrients	BMP evaluation	GIS linkage (freeware)	GUI	GIS database dependent	Public domain availability	Data requirements	Modelling experience
FLUX32	**3**	**3**	**1**	**3**	**4**	**4**	**2**	**4**	**3**	**1**	**1**
LOADEST	**3**	**3**	**1**	**3**	**4**	**4**	**4**	**4**	**3**	**1**	**1**
NEAP	**3**	**1**	**2**	**3**	**3**	**4**	**3**	**4**	**4**	**1**	**1**
N-SPECT	3	1	3	2	1	3	3	3	3	3	2
GWLF	3	2	3	3	3	3	3	2	3	3	3
BasinSim	3	4	3	3	3	3	3	2	3	3	3
NANI	2	-	3	3	3	3	4	3	3	3	2
ReNuMa	2	1	3	3	3	3	4	4	3	3	2
WARMF	3	4	3	3	3	3	3	2	3	3	3
INCA	3	3	3	3	3	3	3	3	3	3	3

3.5 CONCLUSION

With the exception of the low complexity models, all of the remaining models have software or data requirements that were beyond the scope of this assessment. Deriving much of the needed data and information would require a detailed spatial landuse catchment audit (for example, actual details of fertilizer application, soil types, soil elution parameters, number of dairy animals, grazing animals, etc.). While locally-applicable derivatives of some of the models could be created for local use, this would require a not-inconsiderable period of research, data collection and testing in order to do so. Importantly, said derivatives would require input data pertaining to soils, runoff, export coefficients and landuse, details that are not readily available. Additionally, the resolution of the data in the DWS databases is relatively coarse when compared with the input requirements of most of the available tools.

As alluded to earlier in this assessment, the parlous state of reservoir limnology in South Africa constrains the application of the TMDL approach in that, in order for the TMDL to be effective, it needs to be founded on a solid understanding that the waste load reduction will bring about a desired in-reservoir condition. As such, the reservoir-specific load response characteristics need to be known, as well as load contributions from all auto- and allochotonous sources. It is, however, highly probable that the bulk of most South African eutrophic reservoirs derives from wastewater and urban runoff, with wastewater being the major contributor. Common sense, therefore, dictates that attention should primarily be focussed on the attenuation of pollutants of wastewater origin. Such a focus accords with the Polluter Pays Principle in that every person who makes use of a toilet linked to a reticulated sewage system, is a polluter. Many if not most of such polluters live far from the impact of inadequately-treated wastewater disposed of to watercourses and, in fact, may never visit the reservoir where the impact manifests.

Of all the models assessed, the INCA-P model appears to be the most versatile and adaptable for local use. It can be used for first order or more complex interpretations.

3.6 REFERENCES

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4 LOAD ALLOCATIONS BY SOURCE

4.1 The concept of a 'Rapid TMDL'

The nature of a TMDL is that it provides a legally-enforceable rule by which authorities can regulate individual sources of an aggregate TMDL amongst all sources contributing thereto. In its optimal form, this implies that the TMDL is informed by not only the advanced level of limnological understanding alluded to above, but also a comprehensive knowledge of the temporal contributions of each and every contributor (individual source) to the total load. The latter implies the need for equally comprehensive and directed water quality monitoring for each and every source, inclusive of the difficult to estimate or monitor 'non-point' sources. Should such a level of detail not be available then the TMDL may be prone to legal challenge as to its accuracy and relevance.

The aforementioned brings to focus the obvious skills and cost-related constraints of applying a TMDL at a high level of confidence. It is deemed highly unlikely that such TMDLs will be at all possible in South Africa in the short to medium term. By contrast, however, the formulation of TMDLs that provide much needed catchment-level management guidance, in terms of focussing on attenuation of the major sources, should be almost immediately possible. The approach is critically constrained by the absence of a developed and practiced reservoir management program.

Using contemporary South African water resource management parlance, such a solution could be termed "Rapid TMDLs". The TMDLs in this assessment are based entirely on the reduction of nutrient loads, in this case phosphorus, to achieve a desired endpoint that is based on a generic examination of TP:Chlorophyll load:responses in South African reservoirs (Rossouw et al. 2008). Importantly, it makes no assumptions regarding the manner in which the reservoir may or may not respond to the simple reduction of nutrient loading – the latter requiring a considerably more detailed limnological examination of the waterbody.

4.2 Nature of the TMDLs in this study

This study has examined two TMDL scenarios, these being: (a) the upper Berg River, this being a 4000 km^2 watershed that is, in the main, impacted by urban (Franschhoek, Paarl and Wellington) and industrial development and, to a lesser extent, agriculture (**Figure 4-1**); (b) the upper Riviersonderend, largely comprising 500 km^2 of watershed draining to the

Theewaterskloof Dam, a largely undeveloped mountainous catchment with elements of agriculture (fruit farming) and a single town, Villiersdorp (**Figure 4-2**).

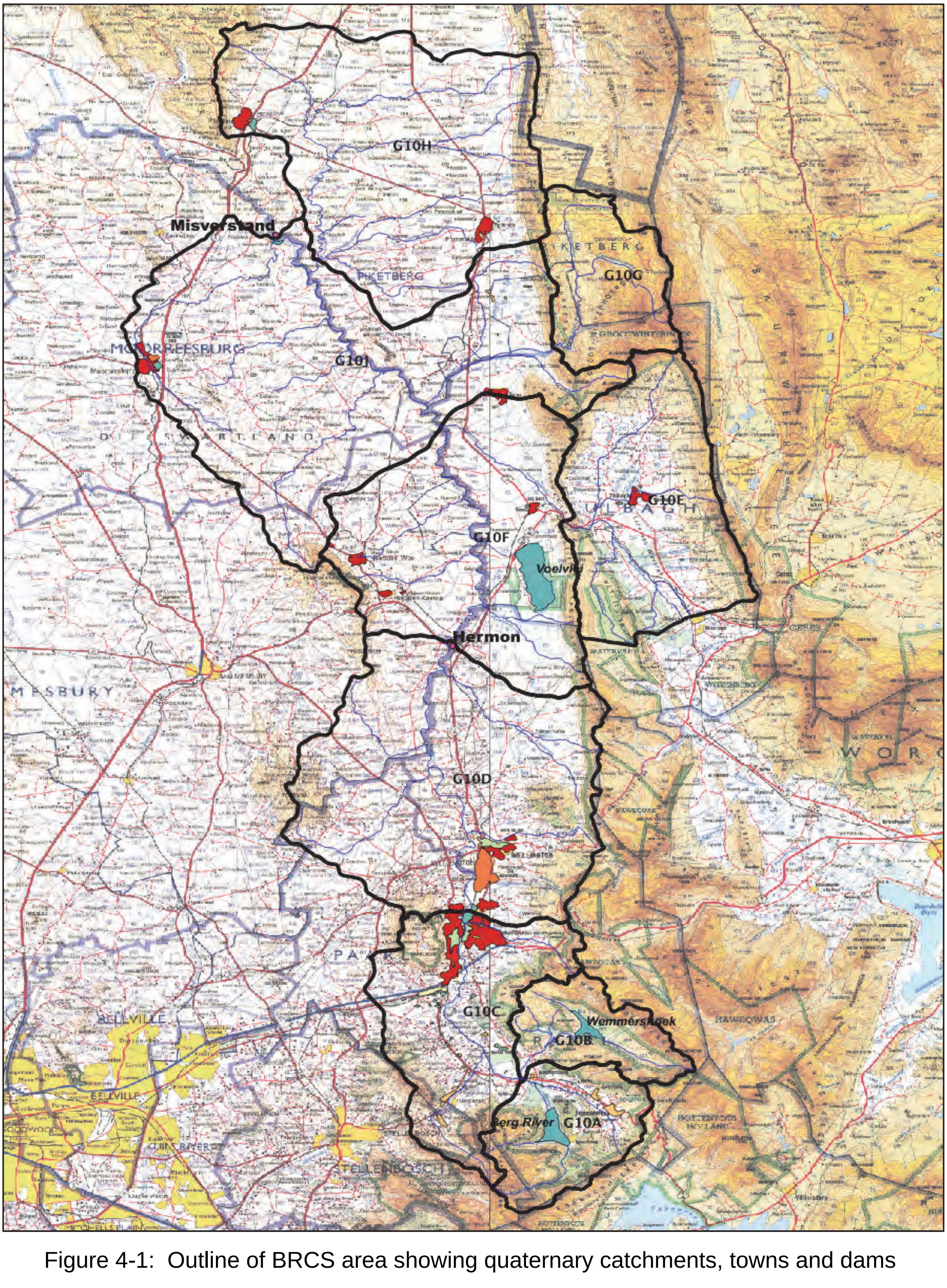

Figure 4-1: Outline of BRCS area showing quaternary catchments, towns and dams

Figure 4-2: Outline of RSECS showing quaternary catchments, towns and dams

The formulation of the TMDLs in this study is focussed on the attenuation of eutrophication and with phosphorus, as Total P, being the element and elemental form of choice. The Berg River Case Study provides an example of a TMDL likely to be primarily founded on point sources of nutrient generation, whereas the Riviersonderend example is deemed to be a non-point source Case Study that may, however, be dominated by the wastewater effluents generated by Villiersdorp.

4.3 TMDL formulation stages

The generation of a TMDL encompasses the following stages or components (**Figure 4-3**):

1. The classification of a specific waterbody as impaired for a specific reason or reasons. This classification would typically arise from a prior, separate process of monitoring and assessment, the outcome of which would flag the need for management intervention. Included in the possible toolbox of management interventions might be the need to ameliorate a set of conditions influenced by, for example, excessive nutrient loading by a specific element or elements (in this assessment phosphorus is used as the example). The process leading to the flagging of such a condition would, based on a detailed understanding of the hydromorphological, climatic, physico-chemical and biological characteristics of the

waterbody, derive a specific requirement that would form the basis of the TMDL, or TMDL 'rule' (Figure 3, Problem Statement).

2. The derivation of a nutrient (or other parameter) load balance for the watershed, focussing on one or more points at which the outcome of the TMDL intervention would be monitored. In the case of a nutrient-based TMDL, for example, this would be a monitoring point at which the outcome of the TMDL could be clearly discerned through monitoring of the product of elemental concentration and flow (Figure 4-3, Numeric Targets).
3. An audit of all sources of the target pollutant within the watershed, translated into loads per source. In the case, for example, of a TMDL aimed at modifying pH, the TMDL would need to focus on those physico-chemical and/or biological (e.g. plant-driven photosynthesis) parameters driving pH (Figure 4-3, Source assessment and Linkage Analysis).
4. An allocation of required reductions to be achieved at each identified source (Figure 4-3, Load Allocations).
5. Implementation of the TMDL, monitoring of its effectiveness and further refinement as and where necessary (Figure 4-3, Monitoring Protocol).

This project focuses essentially on Stages 1-4, as above, examining the ease with which these can be achieved using existing data and tools.

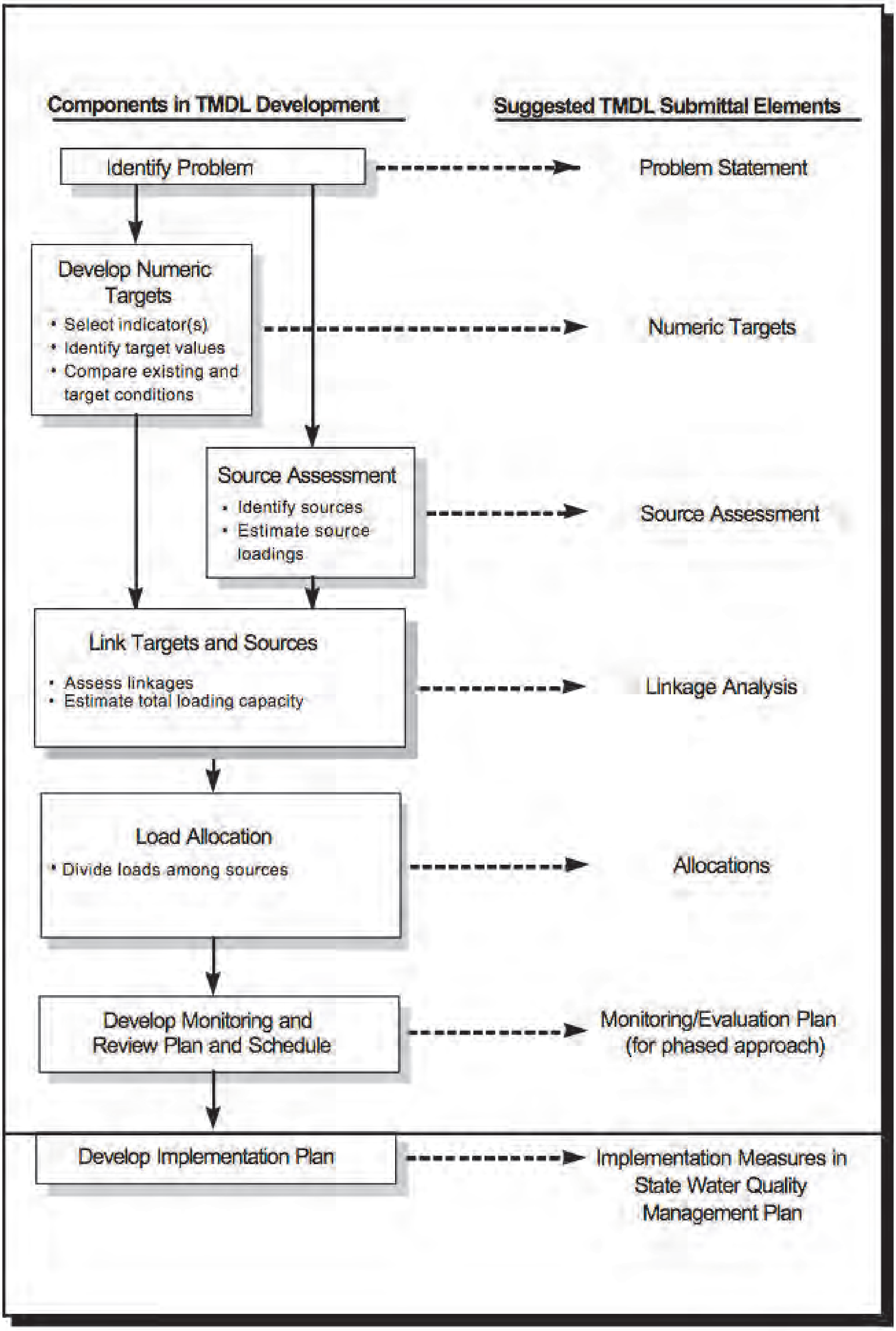

Figure 4-3: Outline of TMDL process

4.4 Basis for the TMDL rules

As indicated above, almost none of South Africa's reservoirs benefit from a level of limnological analysis and modelling necessary to inform high-level management directives based on the management of specific elements or parameters. Certain key reservoirs have, however, provisionally been assessed in terms of their trophic state and, in terms of Total Phosphorus, the level of reduction needed to achieve a generic level of nutrient availability that will reduce the frequency and magnitude of noxious cyanobacterial blooms (Harding 2008). If phosphorus is considered as a proxy for the cocktail of pollutants typically present in wastewater effluents then, given that it is one of the more difficult elements to attenuate, its management should provide a similar degree of reduction of these pollutants currently entering raw potable and/or agricultural water resources.

The Berg River TMDL (for this study) is predicated on the (example) reduction of the annual phosphorus load to the Misverstand Dam being reduced by 17 000 kg P per annum (identified by the aforementioned Harding 2008 study), this required in order to achieve an in-lake summer season TP concentration of 0.045 mg litre^{-1} or less (see Rossouw et al, 2008). Achievement of the reduction is to be measured at the nearest upstream DWS monitoring station, namely that at the town of Hermon. This Case Study thus provides an example of a relatively simple scenario comprising a small, instream reservoir.

By contrast, the Riviersonderend Case Study poses a more difficult challenge: not only is the example likely to be based on non-point sources of pollution arising off a largely natural watershed, the Theewaterskloof Dam comprises two, essentially separate compartments (basins), the upper basin impacted by agriculture and the lower basin impacted by Villiersdorp. DWS monitoring targets the lower basin, whereas data for the upper basin need to be determined from the quality of raw feed water delivered to water treatment plants in Cape Town. Additionally, the hydrodynamic and other complexities posed by the Theewaterskloof Dam precluded it from being included in the aforementioned TMAPL study. For the purposes of this assessment, the focus has been on determining the nature and components of the aggregate nutrient load to the dam and the relationship thereof to the in-lake conditions.

The provisional TMDL rule for Theewaterskloof recommends that the in-lake summer season TP be maintained at 0.030 mg TP litre^{-1} or less, i.e. to maintain the status quo. This value, being 0.015 mg litre^{-1} lower than that is suggested on the basin of the morphology of the dam, i.e. a shallow, dual basin environment that has been prone to cyanobacterial blooms since commissioning. Further data and information regarding the in-lake conditions are provided elsewhere in this report.

4.5 CASE Studies

Berg River Case Study (BRCS)

The BRCS, in terms of nutrient load generation, comprises the section of river between Franschhoek (Franschhoek River) and Wellington, the downstream point being the outfall of the Wellington wastewater treatment works (WWTW). For the purposes of this study, the attenuation of nutrient loading, as TP, arriving at the Misverstand Dam, was taken as the required load reduction. Per Harding (2008), a 37% reduction in extant loading is indicated, this equating to 17 000 kg per annum. The Misverstand Dam is, morphologically, a relatively simple impoundment, rendering the 2008 results of Medium to High Confidence for a Rapid TMDL. In terms of monitoring the achievement of the TMDL, the DWS monitoring point at Hermon has been selected.

A recent nutrient-loading estimate for the affected reach of the Berg River (Harding 2013) estimated the total TP load between the source and Hermon to be 92 000 kg per annum. After allowance for TP removed in run-of-river abstraction, the nett load at Hermon was calculated as 71 tonnes (71 000kg) TP per annum.

The BRCS contains two large WWTWs (Paarl and Wellington), a smaller plant at Franschhoek which, at time of compiling this report is being decommissioned, smaller plants at various estates, typified by small and highly-seasonal flows, and WWTWs servicing smaller towns downstream of Hermon, the effluents from which (reportedly) do not enter the Berg River). At time of writing, a new plant is being planned for the Paarl South industrial area.

Riviersonderend Case Study (RSECS)

The RSECS comprises the headwaters of the Riviersonderend and Van Wyks Rivers, both of which discharge into the Theewaterskloof Dam after relatively short passage through largely undeveloped catchments. The RSE catchment contains a large element of fruit farming. As such the dam is surrounded to the west and southwest by agriculture (fruit farming), to the north by a conservation area, to the north-east by small farms and Villiersdorp and to the southeast and east by a resort, a golf estate and undeveloped land.

The catchment contains a single medium-sized WWTW at Villiersdorp. Various septic and package wastewater processing units exist in the catchment contributing an unknown amount of nutrient loads that may reach the dam. An audit of these and their likely contributions was beyond the scope of this assessment and, indeed, not required for a Rapid Assessment unless otherwise indicated (i.e. a need to include known and previously-flagged sources of pollution).

There is a second, small impoundment in the catchment, in the headwater zone of the Elands River (H60C). For the purposes of this assessment, this dam was deemed to be a trap for any particulate-borne phosphorus generated upstream thereof, and with nil significant TP loading emanating therefrom. Water quality issues on the Elands River arise at the point at which the WWTW load from Villiersdorp is introduced.

4.6 Experimental procedures

Data set constraints

The availability of data for this study was limited, in the main, to that provided by the DWS databases. While relatively comprehensive landuse data are available (kindly provided by the Department of Agriculture: Plant Protection Institute), there are no reliably developed export coefficients associated with runoff and soils from which non-point source loads may be derived. Similarly, there are no data that provide guidelines for runoff from various types of agricultural practices and/or animal husbandry. While the SA Climate Atlas (Schulze) ostensibly provides information that may inform the TMDL process, the electronic version of the atlas is based on an outdated and outmoded set of software – rather than on an infinitely more desirable platform-independent formulation. This precludes direct abstraction of data for use by modelling and/or nutrient load estimation tools.

Attempts to obtain climatic (rainfall and runoff data) directly from the authors of the Climate Atlas met with no success – the requests for assistance were quite simply ignored. With respect to requests for details of water volumes abstracted for irrigation for the Berg River and Theewaterskloof Irrigation Boards, no information was received despite repeated requests accompanied by a formal Letter of Introduction provided by the Water Research Commission.

By contrast, the availability of data for WWTW effluents was readily available from the various local authorities and municipalities.

Use of available models

As discussed in Section 3, a variety of USA-developed modelling tools exist. Almost without exception, these are designed to draw on specifically-formulated databases or make use of state- or regionally-relevant information. While, in some cases, it would be possible to construct databases of South African information that could be used by these models, this was beyond the scope of this assessment.

With respect to the determination of component loads based on discharge and concentration, two models – FLUX32 and LOADEST – both 'by permission' freeware, proved both useful, easy to use and accurate. Using data from the DWS database, these models underpinned the formulation of the BRCS TMDL. Both models build a calibration set based on matched flow and concentration data and then "infill" (estimate) the loads on all days for which only flow data are available – using a flow-weighted approach. This approach is somewhat constrained by the need for the calibration set to span a range of flows – whereas some of the data available to this study tended to lack concentrations measured during high flows. This was, however, offset by the tendency of TP concentrations to be independent of flow (Ward et al, 2010).

The LOADEST model is somewhat complicated for general use in that it is a FORTRAN-based, command-line executed program, whereas FLUX32 is directly-useable via a Graphical User Interface (GUI) (see Section 3). Additionally, FLUX32 is extremely versatile in terms of the range of calculation options, including flow stratification, that it offers.

As both tools require the input files prepared in a specific format, a data processing routine was compiled for this project to extract hydrological and water quality data from the DWS database and create the input (calibration and estimation) input files. The outputs from each programme were compared with manual calculations using the same data and found to be 100% accurate.

Export coefficients

No information on the export of specific elements or pollutants, based on landuse type, is available for South Africa. With respect to TMDLs, this is a critical shortcoming for catchments where non-point source pollution predominates or forms a large portion of the total load. In the absence of national data, use was made of coefficients as published by Kadlec and Knight (1996). The author of this project has, over twenty years of experience in the field of wetland-based nutrient attenuation, found these coefficients to be generically applicable in South Africa. The loads for various indicated landuse types are shown in **Table 4-1**:

Table 4-1: Export coefficients for Total Phosphorus and Orthophosphate

Export coefficients for Total Phosphorus and Orthophosphate per Kadlec and Knight (1996, Table 18.7)

Constituent	Loading rate (kg ha^{-1} yr^{-1})				
	Urban	Industrial	Residential	Agricultural	Natural
Ortho-P	ns	1.3	0.6-3.3	0.9	0.004-0.008
TP	3.4	2.3-3.1	1.4-4.9	1.4	0.04-0.12
ns = not specified					

BRCS: Load estimations per catchment sector

The BRCS catchment was divided into sectors based on the location of DWS water quality and flow-monitoring stations. Annual and seasonal loads were then determined based on the creation of calibration files for each sector and the loads and percentage-based contributions then generated using FLUX32. The aggregate load arriving at Misverstand Dam, inclusive of an estimate of load reduction to irrigation, was then determined.

A second approach was then applied, viz. the determination of the total background watershed P runoff, based on generic export coefficients for natural land surfaces (Kadlec and Knight, 1996, see Table 4-1). This total was then subtracted from that determined above, thus disaggregating the background and anthropogenic loads.

RSECS: Load estimations per catchment sector

The RSECS presented a very different challenge in that the only flow-based load determination was limited to a single point, viz. the outflow from the Villiersdorp WWTW.

<u>Conversion of orthophosphate data to Total Phosphorus</u>

As indicated in the foregoing rationale, attenuation of phosphorus provides the parameter of choice against which the value of individual attenuation efforts can be measured. In this regard, most modelling approaches consider Total Phosphorus as the elemental form to be used in calculations. For this particular study, Total Phosphorus (= TP) data were only available for the Hermon monitoring point, and ortho-phosphate (~ biologically-available phosphorus, = O-P) data for both Hermon and Dal Josaphat. The estimation of TP was undertaken based on the following assumptions:

- For wastewater (WWTW) effluents, O-P forms the bulk of the TP content, typically considered to be [O-P ≈ 90% TP];
- The relationship between TP and O-P, derived from the 2008-2012 DWA data, was compared with the national median level, derived from an analysis of all river data kindly undertaken by Dr M Silberbauer (DWA, Resource Quality Services, Roodeplaat) (see **Figure 4-6**). The latter relationship shows that O-P instream approximates 47% of the TP concentration. At Hermon, the ratio was found to be 57%. For all estimates in this study a working ratio of 50% O-P:TP was used to convert O-P to TP values.

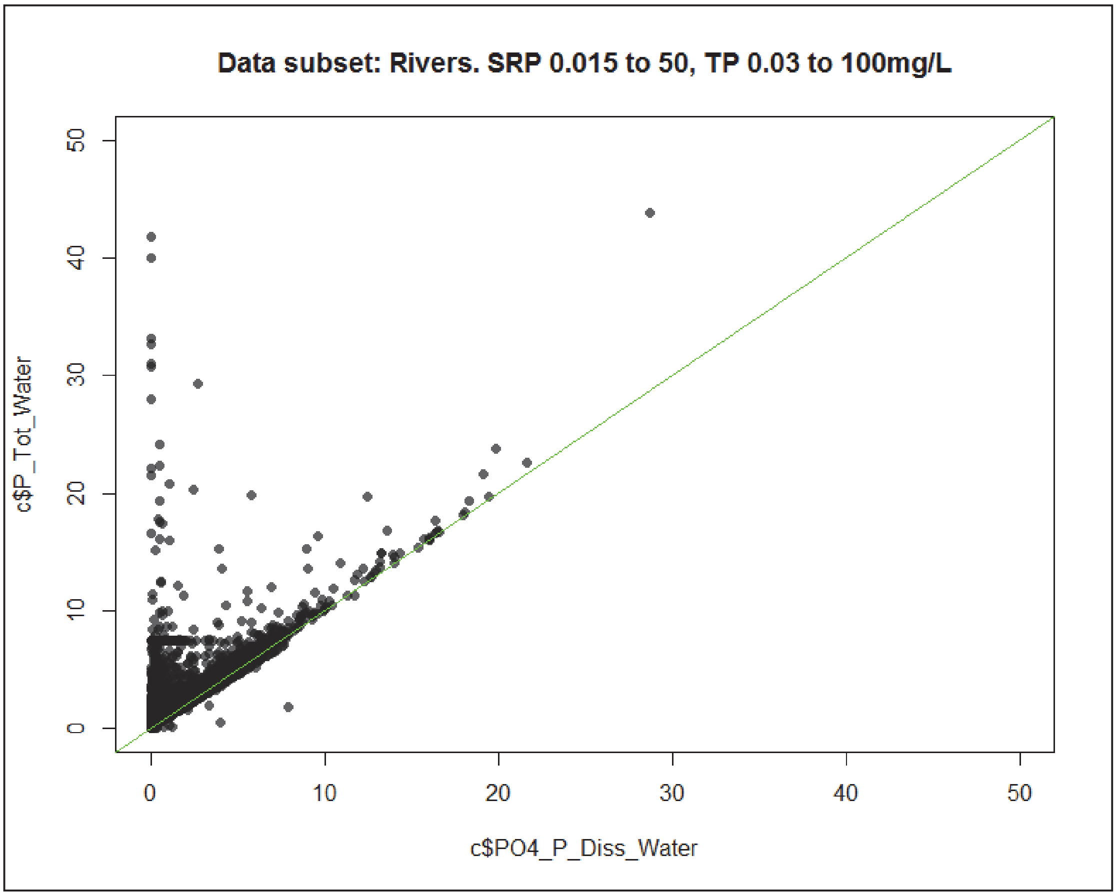

Figure 4-4: Relationship between orthophosphate phosphorus (O-P) and Total Phosphorus (TP)

(Dataset = all South African rivers, DWA-WMS database. Source: Dr M. Silberbauer, DWA/RQS, Roodeplaat.)

Reservoir conditions

In keeping with the need to derive TMDLs based on existing data, the conditions in the Misverstand Dam (Berg River) were accepted as being those derived by Harding (2008). For the Theewaterskloof Dam, not included in Harding (*ibid*), a similar nutrient loading and response model, based on the Walker Reservoir Model (see Harding, *ibid*) was compiled – i.e. the same approach as adopted for the 2008 study. This model was calibrated using water quality data for various sections of the dam provided by the Scientific Services Department, Water and Sanitation, City of Cape Town. Insofar as phosphorus is concerned, these data reflect the following in-lake conditions (**Table 4-2**):

Table 4-2**:** Total phosphorus in-lake concentrations for Theewaterskloof Dam

Total phosphorus concentrations for Theewaterskloof Dam (2010-2014)
(Source: City of Cape Town, Scientific Services)

Sector of Dam	Median TP (mg litre-1) Ortho-P in ()	75%ile TP (mg litre-1) Ortho-P in ()
Nature Reserve (Northwest)	0.027 (0.010)	0.039 (0.010)
Intake Tower (West basin)	0.026 (0.001)	0.030 (0.003)
Inter-basin channel	0.024 (0.001)	0.026 (0.001)
Dam Wall (east)	0.023 (0.001)	0.029 (0.010)
Yacht Club (north, east basin)	0.023 (0.001)	0.031 (0.001)

Data for the period 2010-2014, provided by the City of Cape Town.

These data reflect a relatively constant across-lake level of phosphorus, although slightly higher in the eastern basin – which is contrary to what was initially-expected given that the urban sources of pollution discharge to the latter. Phytoplankton development is P-limited. As above, however, it should be noted that this impoundment develops regular, low-level yet problematical summer blooms of a filamentous cyanobacterium (*Anabaena solitaria* var *catenula*). As such it is assumed that the severity of such blooms would increase should phosphorus availability increase.

4.7 Suggested TMDL 'rules'

The suggested TMDL rules, for the illustrative purpose of guiding this assessment, are as follows (in abbreviated format):

Berg River CS

The BRCS TMDL must enable a reduction in the total phosphorus loading to the Misverstand Dam of greater than or equal to 17 000 kg TP per annum. This reduction is to be derived in the watershed at or upstream of Wellington. The achievement of the TMDL is to be monitored at the DWS Hermon monitoring station on the Berg River, as well as in the effluents of any or all point sources identified for attenuation.

Riviersonderend CS

The RSECS should ensure that the spring/summer in-lake concentration of phosphorus in the Theewaterskloof Dam does not rise above a 50%ile or 75%ile concentration of, respectively, 0.030 and 0.040 mg per litre. Alternatively that the phosphorus loading does not increase above 2014 levels.

4.8 Results, treatment of results and discussion

Landuse Assessment

A fundamental point of departure of the TMDL process is an audit of the watershed in terms of landuse, i.e. identification of the likely sources of pollutant generation. This project has undertaken this assessment at broad level – based on landuse mapping as derived by the Department of Agriculture. The results of this assessment are provided below.

Berg River Study Area

The Berg River study area comprises 4000 km^2, spanning 9 quaternary drainage basins The principle landuse categories and areas, expressed as a percentage of the total, are summarized as follows (see also **Figure 4-5**):

- Natural vegetation: 32.6%
- Forests: 2%
- Waterbodies/wetlands: 1.2%
- Dryland agriculture: 54.3%
- Irrigated agriculture: 8.2%

- Urban/industrial: 1.5%

This catchment is characterized by high dryland agriculture and low urban area components.

Riviersonderend Study Area

The RSE study area comprises 498 km^2, spanning 3 quaternary drainage basins. The principle landuse categories and areas, expressed as a percentage of the total, are summarized as follows (see also **Figure 4-6**):

- Natural vegetation: 66.6%
- Forests: 0.9%
- Waterbodies/wetlands: 13.6%
- Dryland agriculture: 4.6%
- Irrigated agriculture: 13.8%
- Urban/industrial: 0.5%

This catchment is characterized by high natural vegetation and low urban area components.

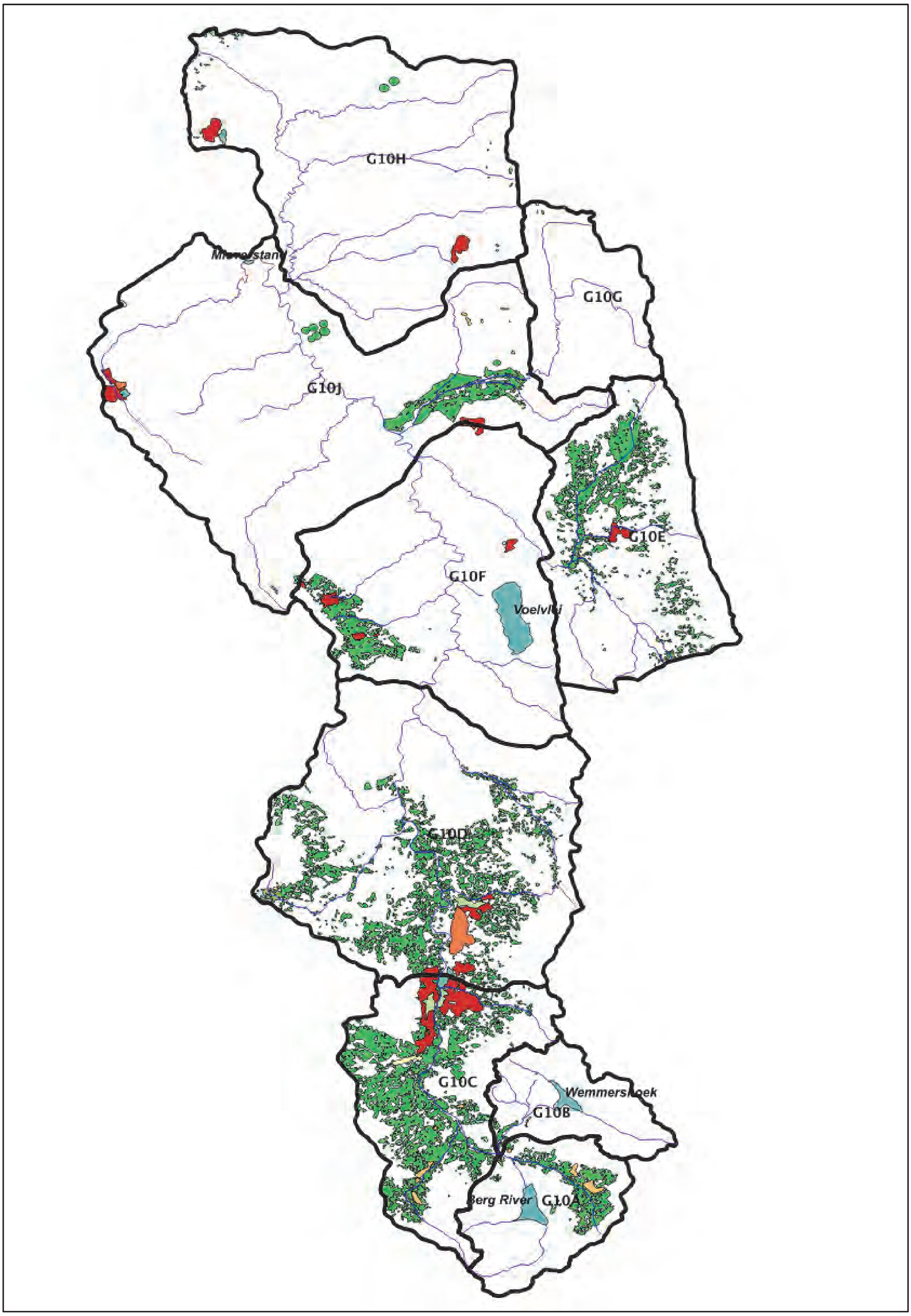

Figure 4-5: BRCS irrigated landuse areas

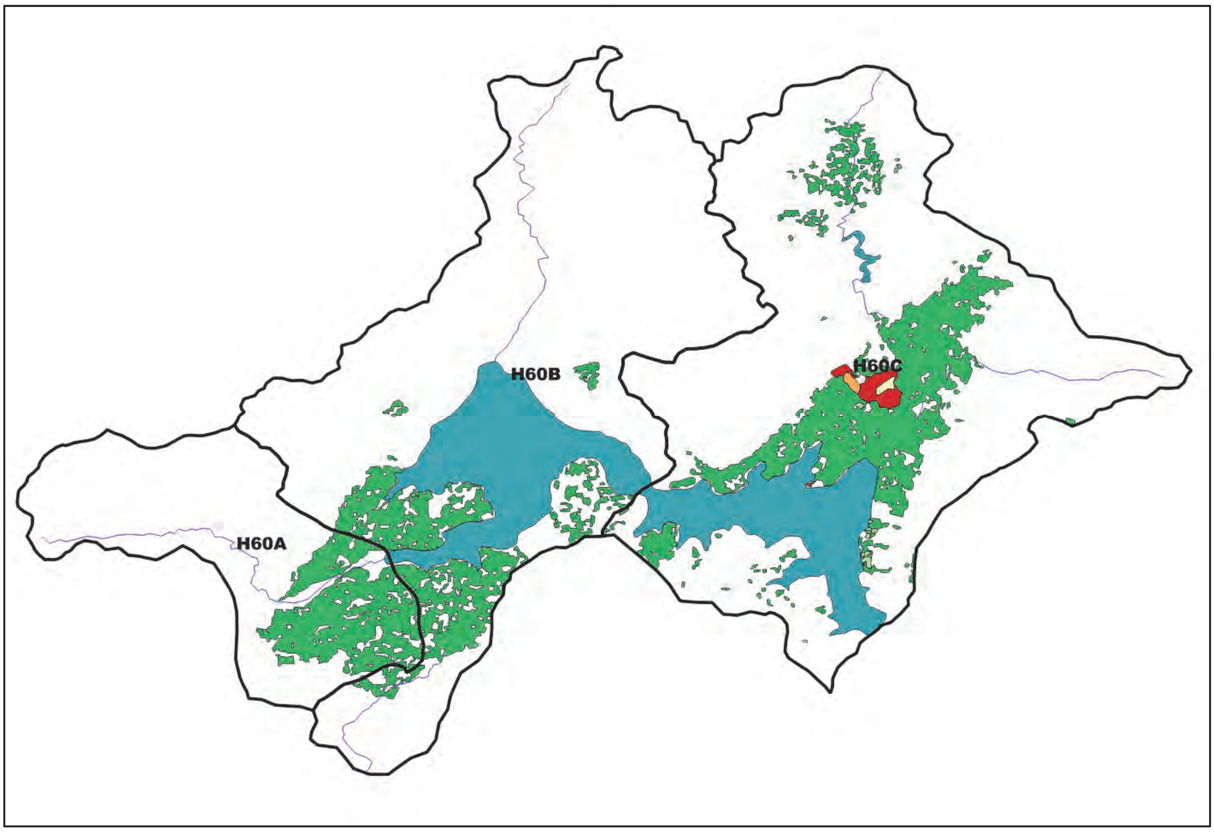

Figure 4-6: RSECS irrigation landuse

4.9 BRCS Phosphorus load generation

Urban and point sources

River-borne phosphorus loads for sections of the river mainstem and tributaries were determined using data from DWS discharge and water quality monitoring stations. Wastewater loads from WWTWs were determined using data provided by the individual facilities. Loads were calculated using the FLUX32 software, as annual and seasonal (winter/summer) for the period 2000-2010 (see **Table 4-3**).

Table 4-3: Berg RIver Annual TP load estimation

Berg River Case Study: Annual loads per estimation point					
LOCATION	**TRIBUTARY**	**WWTW**	**LOAD**	**TOTAL**	**VARIATION**
Dal Josaphat			31200	31200	
		Paarl	51000	82200	
		Wellington	21000	103000	
	Doring		960	104160	
	Kompanjes		2800	106960	
Run of river irrigation abstraction (estimated)			-42000	64960	
Hermon				**52000**	-12960
	Vis		800	52800	
	Koringberg		7200	60000	
	Matjies		3200	63200	
Run of river irrigation abstraction			?	33200	
Misverstand				46000	+12800

This analysis (based on three separate sources of data) overestimates the load arriving at Hermon, but underestimates, by almost the same amount, that at Misverstand. The load balance is, however, compromised by the lack of any reliable irrigation abstraction data, either up- or downstream of Hermon. Throughout, however, it should be borne in mind that while the effect of the TMDL is to be at Misverstand, it is to be achieved at Hermon.

BRCS Background loading

The background TP loading for the BRCS was determined per quaternary catchment and then aggregated. As a first step, the loads were determined using the lower TP export coefficient value for natural landuse (see Table 4-1) for all quaternaries in which irrigated agriculture was not dominant. For the latter, the higher value (Table 4-1) was used. The agriculture practiced in these catchments is, primarily, fruit and viticulture. These practices are not associated with high runoff and as the irrigation is primarily in the dry summer season, it is not anticipated that significant return flows from irrigation occur – i.e. there is no indication for a higher value of export coefficient to be employed.

Based on the above approach, the following loads per BRCS quaternary were derived (Table 4-4):

Table 4-4: BRCS TP loads per quaternary catchment

BRCS quaternary-based annual TP loads						
Quat	MAR (mm)	Area (km^2)	Irrigated Y/N	Low Load	High Load	Mixed Load*
				Kg per year		
G10A	1015	172	Y	687	2061	2061
G10B	726	126		504	1512	504
G10C	448	328	Y	1312	3937	3937
G10D	168	688	Y	2750	8250	8250
G10E	173	394	Y	1576	4729	4729
G10F	113	539		2157	6472	2157
G10G	668	186		742	2227	742
G10H	31	675		2698	8094	2698
G10J	40	868		3470	10410	3354
			TOTAL	15898	47693	28433

Loads determined using 0.04 kg/ha/yr for quaternaries lacking dominant irrigated agriculture or irrigated agriculture located far from the river mainstem. For catchment with substantial irrigated agriculture, an export coefficient of 0.120 kg/ha/year was used. *The 'Mixed Load total was derived as the sum of the Low Loads per non-irrigated quaternary and the High Low in the Irrigated cases.

Provisional comparison of load composition

The key load 'checkpoints' in the BRCS are upstream of Paarl (Dal Josaphat), i.e. upstream of the influence of the Paarl and Wellington WWTWs, at Hermon and at Misverstand.

The total loading upstream of Paarl, i.e. that determined using FLUX32, is 31200 kg TP annum^{-1} (Table 4-3), of which the background load is 6189 kg (Table 4-4). Downstream of Wellington, taken as the outlet from G10D, the total load is 103 000 kg TP annum^{-1}, of which the background component was estimated as 14752 kg TP annum^{-1}. As such, the difference between the total load and that derived from wastewater (72 000 kg TP annum^{-1}) and background, i.e. the unallocated load, is 16248 kg TP annum^{-1}.

Within the three quaternaries G10A-C of the BRCS study area, the area categorized as urban and industrial landuse, equates to 26 km^2. From Table 1, using a TP export coefficient of 3.4 kg ha^{-1} yr^{-1}, yields 8840 kg TP per annum derived from urban landuse. This approximates 50% of the unallocated load expressed above, suggesting that the choice of runoff coefficients for natural landuse are reasonably accurate for the purposes of this study.

If the 26 km^2 are removed from G10C, the quaternary that contains the bulk of the urban landuse, then Table 4 can thus be amended as follows (see Table 5):

Table 4-5**:** BRCS amended TP loads per quaternary

BRCS quaternary-based annual TP loads, amended to separate urban-specific loading from G10A-C						
Quat	MAR (mm)	Area (km^2)	Irrigated Y/N	Low Load	High Load	Mixed Load*
				Kg per year		
G10A	1015	172	Y	687	2061	2061
G10B	726	126		504	1512	504
G10C	448	302	Y	1208	3624	3624
G10C Urban		26			8840	8840
G10D	168	688	Y	2750	8250	8250
G10E	173	394	Y	1576	4729	4729
G10F	113	539		2157	6472	2157
G10G	668	186		742	2227	742
G10H	31	675		2698	8094	2698
G10J	40	868		3470	10410	3354
			TOTAL	15793	56220	36961

Loads determined using 0.04 kg/ha/yr for quaternaries lacking dominant irrigated agriculture or irrigated agriculture located far from the river mainstem. For catchment with substantial irrigated agriculture, an export coefficient of 0.120 kg/ha/year was used. *The 'Mixed Load' total was derived as the sum of the Low Loads per non-irrigated quaternary and the High Low in the Irrigated cases.

Using the same argument as above, the background and urban allocation at the outlet of G10D increases from 14752 to 23280 kg TP per annum. The unallocated portion now becomes (103000 - 72000 - 23280) = 7720 kg TP per annum or 7% of the FLUX32 derived load at this point in the watershed. This is considered to be an acceptably low variation given the nature of the input data. It also serves to confirm the applicability of the export coefficients in Table 4-1.

A similar 'urban' allocation has not been applied for Riebeek West and Riebeek Kasteel as the urban runoff from these towns does not flow directly to the Berg River.

Seasonality of phosphorus loading

A fundamental characteristic of a TMDL is the ability to disaggregate loads both spatially and temporally. It is assumed that the TMDL rule, in this case derived from an understanding of the nutrient load:biotic response characteristics of the Misverstand Dam, that the rule would specify a period or periods during which the required load reduction should be implemented. For example, in the Western Cape, it could be assumed that the load reduction would be required in the months immediately preceding the spring/summer annual phytoplankton growth phase.

The use of the FLUX32 software allows for the determination of loads based on any specified period of time. As a first step, the loads determined at Dal Josaphat and Hermon were split into wet and dry seasons, with the wet season being October to March and the dry April to September (**Tables 4-6 and 4-7**).

Table 4-6: Annual and seasonal TP loads in the Berg River at Dal Josaphat

Annual and seasonal loads of TP in the Berg River at Dal Josaphat determined using DWS data and FLUX32				
No.	Period	Total Load per hydraulic year, kg per annum	October to March Load, kg per annum	April to September Load, kg per annum
1	October 99 - September 00	19507	3972	15535
2	October 00 - September 01	51795	4159	47636
3	October 01 - September 02	28891	6605	22286
4	October 02 - September 03	16342	6092	10250
5	October 03 - September 04	19327	5444	13883
6	October 04 - September 05	29342	4636	24706
7	October 05 - September 06	27837	5188	22649
8	October 06 - September 07	36175	4607	31568
9	October 07 - September 08	41378	5469	35909
10	October 08 - September 09	40259	11147	29112
11	October 09 - September 10	29101	12436	16665
	Average per hydro year	30905	6341 (20%)	24564 (80%)

Table 4-7: Annual and seasonal TP loads of in the Berg RIver at Hermon

Annual and seasonal loads of TP in the Berg River at Hermon determined using DWS data and FLUX32				
No.	Period	Total Load per hydraulic year, kg per annum	October to March Load, kg per annum	April to September Load, kg per annum
1	October 99 - September 00	38987	9566	29421
2	October 00 - September 01	54744	18526	36218
3	October 01 - September 02	64103	15787	48316
4	October 02 - September 03	31525	12304	19221
5	October 03 - September 04	31535	8287	23247
6	October 04 - September 05	48473	6230	42243
7	October 05 - September 06	46716	5512	41204
8	October 06 - September 07	55268	6160	49108
9	October 07 - September 08	58650	9545	49105
10	October 08 - September 09	73688	13840	59848
11	October 09 - September 10	73385	30445	42940
	Average per hydro year	52461	12382 (23%)	40079 (67%)

In addition to the in-river loads (Tables 5 and 6 above), the seasonality of the wastewater contributions was also determined, using information from Harding (2013) (**Table 4-7**).

Table 4-8: WWTW monthly TP loadings to the Berg River

Monthly loads of TP (2012 year) generated by the Paarl and Wellington WWTWs (data from Harding 2013)			
Month	Load ex Paarl WWTW (kg TP month^{-1})	Load ex Wellington WWTW (kg TP month^{-1})	TOTAL per month
October	3422	1908	5330
November	1701	1670	3371
December	2511	1670	4181
January	3341	1431	4772
February	4111	1431	5542
March	4253	1431	5684
April	4455	1598	6053
May	4658	1670	6327
June	5468	2147	7614
July	6116	2147	8262
August	6176	1908	8084
September	4617	2147	6764
TOTAL	50828	21155	71982

While it is not the purpose of this assessment to examine the nature of the observed seasonality (the purpose being to demonstrate whether or not such seasonality can be readily discerned using available data and tools), the following characteristics are noted:

- There is a marked difference between dry and wet season loads, with the annual loads for the hydrological year split, respectively, in a 20:80% ratio;
- There is a marked inter-annual variation in seasonal and annual loads (see **Figure 4-10**);
- The seasonal variation in loads generated by the Paarl and Wellington WWTWs is considerably less than the ratios observed at Dal Josaphat and Wellington (see Figure x);
- Wet season loads at both stations increased steadily between years 4 and 9 (Dal Josaphat) and 10 (Hermon), while dry season loads remained flat. Thereafter there was a marked decrease in loads at Dal Josaphat, less so at Hermon and with an increase in dry season loads at both stations from year 9 onwards (more marked at Hermon);

- The temporal nature of loads removed from the river through abstraction, as well as via natural instream biogeochemical and other processes, remains an unknown factor.

Insofar as load seasonality for the two large WWTWs is concerned, seasonality was largely absent from the Wellington WWTW, but increasingly steadily between the months of November and August (see Figure 4-7). This ‘trend’ may be an anomaly arising from the use of two short (temporally) a dataset.

Although not utilized in this assessment, FLUX32 incorporates the ability to further separate loads based on flow stratifications, as well as enable a range of data-interrogation procedures.

Note on the Bath (1989) report

In 1989 a Department of Water Affairs project examined the transport of phosphorus in the Berg River (Bath 1989). That report examined P-loads to the Drie Heuwels Weir upstream of Misverstand Dam. While the report found a similar split in summer:winter loads, it maintained that the bulk of the P loading in the river derived from non-point sources, a finding not substantiated by this assessment. If one assumes that the bulk of TP transport off land would be in particulate form then the TP:O-P ratio in stream would be higher than the 1:1 level as reported in this study (see Figure 4-4). The Bath report also made no allowance for P removal from the river via irrigation abstraction.

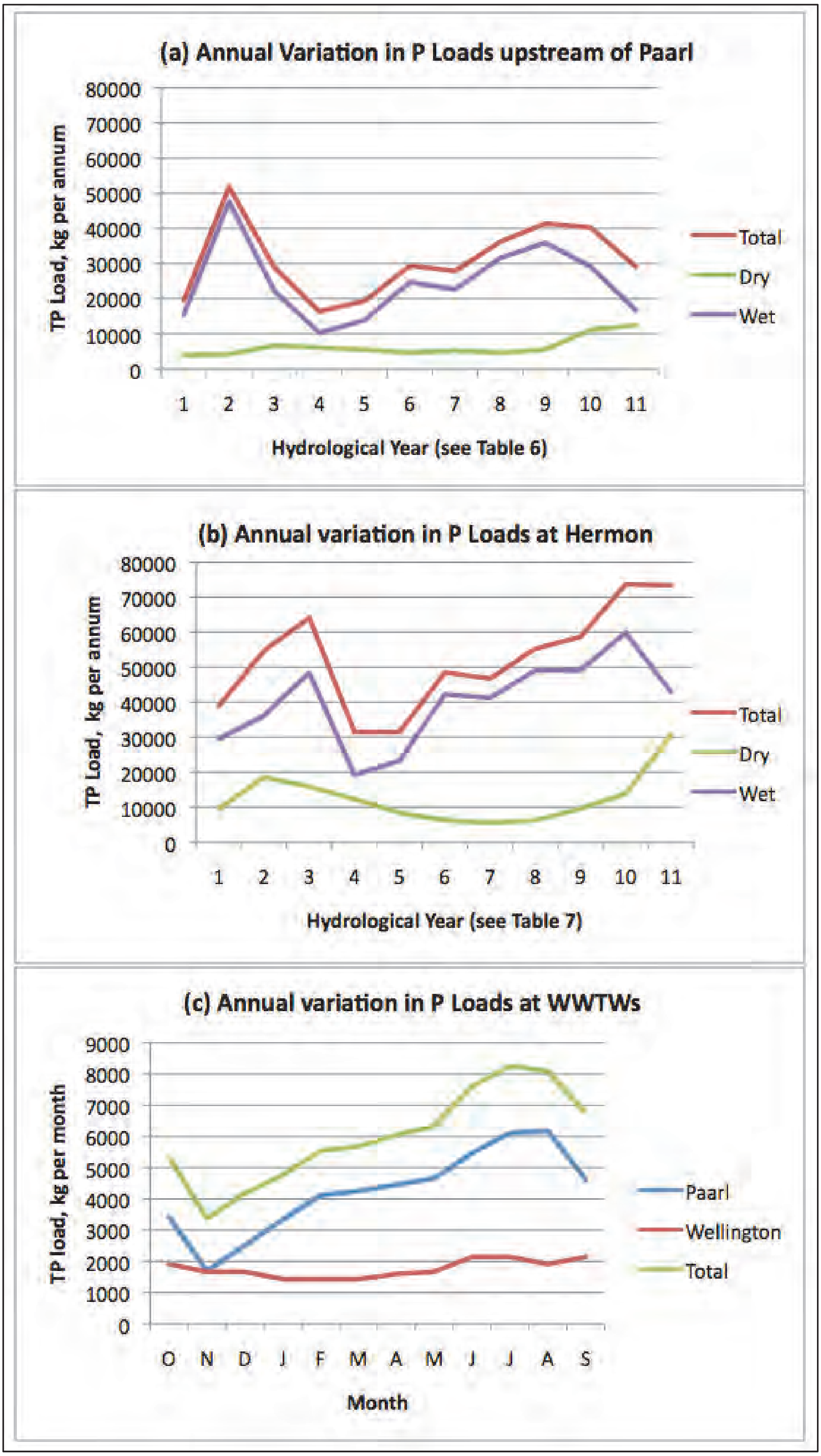

Figure 4-7: Graph showing seasonal variation in phosphorus loads

4.10 Riviersonderend CS

There are no active flow and water quality gauging stations in the RSECS catchment that support the load determination approach utilized for the Berg River CS. The alternative of using a monitoring location downstream of the dam was excluded as this would only focus on released loads, whereas the intention of the TMDL is for the in-lake TP conditions in the dam itself. It was therefore decided to estimate the extant loads associated with the observed in-lake conditions and then relate this to the identified waste and other load allocations arising in the catchment. Using reverse modelling, i.e. determining the phosphorus load necessary to produce the observed in-lake conditions, an annual, flushing-corrected load of 12 000 kg was estimated. This loading is determined assuming a single lake basin of simple morphology. This is not the case and a need for a greater level of modelling sophistication is indicated. However, the data provided by the City of Cape Town (see Table 4-2) indicates a lack of variation in TP concentrations across the dam.

Background loads

Background loads, using a minimum and maximum export coefficients of 0.04 and 0.120 kg per ha per year produced a loading range of between 1988 and 5964 kg per year.

Urban and point sources

As the urban area component of the study area was less than 0.5% of the total, background loads were not disaggregated beyond the determinations using natural background levels.

The Villiersdorp WWTW is the only bulk sewage processing facility in the watershed. Data provided by Theewaterskloof Municipality (TWKM, Mr C van Heerden), for 10 months between May 2013 and March 2014 indicated a range (as orthophosphate-P) of between 1.1 and 4.9 mg P litre^{-1} in the final effluent. Examination of data held by DWS for the period 1999-2014 revealed a median concentration of 6.2 mg P litre^{-1} and an absence of any trend or seasonality in the dataset. The 25th and 75th percentile values were 4.2 and 8.1, respectively, indicating that use of the TWKM data would underestimate the conditions. The Villiersdorp WWTW is, according to the consultancy reports submitted, overloaded. Additionally, a new and large sub-economic housing development is planned, from which will be derived the dual impacts of additional wastewater loading to the WWTW as well as an increase in stormwater runoff to the Theewaterskloof Dam.

In light of the foregoing, the following present-day scenario was utilized, namely allocation of the DWS median concentration to the dry season flows and the 75th percentile value to the wet season. As such, loads from the Villiersdorp WWTW, based on wet and dry season flows of 1100 and 750 m^3 day^{-1}, respectively, yielded a total annual load of 2440 kg as TP.

Combined with the background load range, this reflects an annual loading range of between 4438 and 8404 kg per annum. These totals do not reflect the contributions from agriculture, unmanaged runoff from informal and semi-formal settlements, as well as package plant wastewater effluent from resorts and estates (see **Table 4-8**). These are assumed to be accurately aggregated within the background loading as the difference between the estimated total load and that calculated is approximately 7%.

Table 4-9: Summary of TP loads to Theewaterskloof Dam

Summary of TP loads to Theewaterskloof Dam (RSECS)			
No.	Source	Loading (kg TP per annum)	Total (kg TP per annum)
	Estimated total load to dam		12000
1	Wastewater (median)	2440	
2	Background loading (High scenario)	8404	12850
	Variation		(+850)

Comparison of the combined estimated loading with the reverse modelling of the observed in-lake condition suggests that the upper value of 8404 kg TP per annum is the more accurate. Qualification of this will require the derivation of area-specific phosphorus export coefficients.

The indicated loading of 12 000 kg per annum is based on an in-lake TP of 0.028 mg $litre^{-1}$. The load associated with the indicated target of 0.030 mg per litre would be 12800 kg per annum.

4.11 Summary

The approaches adopted and followed in this assessment strongly suggest that Rapid Level TMDLs can be formulated with relative ease and at low cost. This assumes that an equivalent level of data and information are available. Higher level TMDLs, requiring of a more rigorous disaggregation of flows and loads are possible in cases where detailed hydrological studies have been undertaken, and/or where funds allow for such to be generated on a case-specific basis. Of considerable importance, however, is that the TMDL can only be formulated in response to a requirement (e.g. nutrient loading) that has been rigorously determined – for example the load:response characteristics of a particular waterbody. For the protection of South African dams, for example, the lack of relevant limnological reservoir assessments is the biggest single constraint to the formulation of any level of TMDL higher than a Rapid and in cases where the load:response characteristics of the target waterbody are relatively simple.

The extant and proposed example TMDLs for the two catchments can be structured as follows:

Berg River CS

The required reduction of 17 000 kg TP per annum at Hermon would be easily achieved in the short term at one or both of the WWTWs (Paarl and Wellington). Given the need to minimize nutrient loading in the Misverstand Dam during the summer months, the reduction would likely need to target the six-month period preceding the onset of problematical algal growth (July to December). The precise logistics of implementing the nutrient reduction require (a) more detail re the phytoplankton load:response characteristics in the dam and (b) the nature of the nutrient reduction intervention to be applied.

Monitoring of compliance with the TMDL would need to be at the individual WWTW – at which point a daily TMDL allocation could be envisaged once the attenuation intervention has been compiled. Additional daily data on flows and pollutant concentrations would be required in order to set the specifications of the TMDL. The range of natural fluctuation in loads at Hermon would confound an attempt at compliance monitoring other than in the long-term.

Riviersonderend Case Study

The TMDL assessment has revealed that the necessary intervention should endeavour to sustain or improve the extant TP loading, i.e. there should be no further increase in nutrient loading over that currently estimated. From the findings above it is apparent that a substantial improvement over the extant conditions can be achieved.

4.12 REFERENCES

BATH AJ (1989) PHOSPHORUS TRANSPORT IN THE BERG RIVER, WESTERN CAPE. Hydrological Research Institute Report TR143, Department of Water Affairs, Pretoria.

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WARD ND, RICHEY JE AND RG KEIL (2010) Temporal variation in river nutrient and dissolved lignin phenol concentrations and the impact of storm events on nutrient loading to Hood Canal. 2nd Joint Federal Interagency Conference, Las Vegas NV July 2010.

5 CONCLUSIONS & RECOMMENDATIONS

5.1 Overview

The legislative (enforceable) nature of a TMDL, as is the case for a Comprehensive Ecological Reserve, requires that all components on which the TMDL is based be of an equal and high level of confidence. In the USA, where TMDLs originated, the process has been founded on exhaustive, rigorous and inter-agency efforts to provide such a level of confidence for each of the data and information components. At the present time TMDLs cannot readily be formulated in South Africa beyond the level as described in this study. This does not, however, preclude the determination of higher confidence TMDLs. Most, if not all, of the required information can be obtained and developed as TMDL input data with relatively little effort and cost – a process that could be undertaken nationally or on an *ad hoc* basis informed by prioritized catchment needs. Additionally, the reason for the TMDL must be founded on a separate and equally comprehensive evaluation, for example a reservoir assessment that has identified a specific nutrient attenuation need, with the end result following attenuation, or through phases of attenuation, reliably determined.

The TMDL process, as outlined in Figure 1-1, defines how the Problem Statement and its Numeric Targets relate to the overall TMDL. South Africa currently has xx dams that are eutrophic or hypertrophic (e.g. Matthews 2014; Harding, submitted). The initial process of formulating TMDLs for these, given the absence of detailed limnological assessments for, with three or four exceptions, most of them, could be informed by their prioritization based on economic importance and/or use impairment. At a Rapid level, this has already been done for several dams (Harding 2008). Per Harding (2008), wastewater effluents have been identified as the major source of nutrient loading to the assessed reservoirs, akin to the Berg River / Misverstand case study assessed in this project. As such, TMDLs are not required as the primary intervention – as indicated over more than 30 years (see Harding, submitted) is clearly better management of wastewater effluents. An immediate and substantial intervention could, therefore, be implemented 'overnight' by enforcing the Phosphorus Special Standard. Here it must be acceded that, in cases such as Hartbeespoort Dam, where despite attainment or bettering of the Special Standard, the sheer product of volume and concentration continues to exceed the assimilable capacity of the dam, a much more stringent standard is indicated. In the case of the Berg River, however, a requirement for the Special Standard at Paarl and Wellington would bring about a massive and significant reduction in nutrient loading to the river.

If we assume that the eutrophic and hypertrophic dams are already identified (e.g. per Matthews 2014), then TMDL-based efforts need to focus on those dams that are currently in the mesotrophic or better condition. For this set of dams the eutrophication 'trend' needs to be determined and rules put in place to attenuate progress towards eutrophic. The primary point of departure here would be to use biological indicators (in this case diatoms) to infer, in an accurate and cost-effective manner, Total Phosphorus levels in impoundments (e.g. Bennion et al. 2010; Tibby et al. 2004).

While this study has shown that loads of in-stream nutrient (or, for that matter any other parameter) can be reliably determined using DWS data and software such as FLUX, the need for export coefficients in hydraulically unmonitored catchments is an important need. Given the relatively spatial and temporal distribution of DWS flow monitoring stations, it should be possible to, quite quickly, determine export coefficients for various landuse types and for both historical and contemporary conditions, as well as for variance associated with rainfall and discharge.

It would be possible to automate the generation of elemental loads using data in the DWS database via a web-based application.

5.2 Are TMDL's achievable in South Africa?

It is assumed that, should TMDLs become a facet of the South African Waste Discharge:Charge System or other water resource protection measures, there will be appropriate legislative measures in place to enforce identified polluters to both understand their role and to meet their responsibility. Although determining the ability to comply with the TMDL is not a focus of this study, the following provides an overview of what could be achievable.

In the two test cases undertaken here, it is immediately apparent that more stringent wastewater controls would not only meet but exceed the indicated TMDLs. In both case studies, and especially for the BRCS, very small percentages of urban areas generate very large loads of phosphorus in wastewater. In the case of the Berg River CS, typical median phosphorus concentrations in the Paarl and Wellington WWTW effluents were 6.8 and 8.0 mg per litre (as P), respectively (Section 4). Similarly very high median levels were reported for the Villiersdorp (RSECS) WWTW, namely 6.2 mg per litre as P. Simple implementation of the Phosphorus Special Standard (1 mg per litre as P) would exceed the required load reduction. The requirement could, for example, be 'phased in', with a requirement for a 50% reduction of current loads sufficient to address the immediate TMDL need.

In the case of the BRCS, implementation of the 1 mg per litre P standard would reduce the extant loading from 71 000 to 10 000 kg P per annum, an 85% reduction. The same level of reduction would be achieved at Villiersdorp. There are no societal, scientific or economic reasons why the Special Standard, available as a nutrient management tool since 1985, should not be imposed in the BRCS and RSECS catchments.

The imposition of a similar requirement on all minor WWTWs in the catchment would further reverse the current situation.

Attenuation of WWTW-originating waste loads provides the most desirable means of curtailing anthropogenic impact. Funding the required reduction, via rates and taxes, is likely to be unpopular. However, as every person connected to reticulated sewage is a ‘polluter’, the ‘polluter pays’ principle applies. Of course the impact of wastewater on South African reservoirs and the current level of impairment as a result thereof, needs to be brought to the attention of all South Africans.

Pollution from non-point sources, over and above background loads, is considerably more difficult to manage or enforce – other than through incentives. A common thread in TMDL interventions is that everyone – i.e. point and non-point source polluters, should be treated equally in terms of reducing the target load. While this is morally admirable, it is both pragmatically and practically impossible to achieve for non-point sources in the short to medium term. It will be very difficult to persuade the agricultural sector of the need for preventing nutrient runoff to rivers without comprehensive evidence having been gathered. It is also unlikely that, in the present economic climate, farmers will ‘waste’ fertilizer through improper application. Equal treatment cannot be used as an excuse by WWTWs (local authorities) to not make any changes until such time as agricultural BMPs, and the onerous monitoring required to track their success or failure, are in place. This would take years and simply countenance further massive WWTW-effluent based degradation of both watercourses and reservoirs.

In the two cases tested here, there is no indication that agriculture is a major contributor to nutrient pollution of either system, although this requires a greater level of hydrology detail to confirm. In point of fact, it appears that run of river abstraction may be removing considerably more phosphorus than is contributed by agricultural practices – i.e. that farming could be acting as a nett sink of phosphorus, rather than as a source. This remains to be tested once appropriate data are available.

5.3 Summary

This project has provided yet another indication of the need for better management of wastewater effluents, in particular nutrient attenuation. This call has been stated time and again over three decades but, apart from the promulgation of the Special Phosphorus Standard, has yet to be widely, if at all, heeded in terms of enhanced treatment processes (Harding, submitted).

In terms of the objectives of South Africa's integrated pollution and waste management policy, it is clearly implicit that waste reduction at source is the central norm – particularly in points (iii) & (iv) (DEAT 2000):

i. To promote cleaner production and establish mechanisms to ensure continuous improvements in best practice in all areas of environmental management;
ii. To prevent, reduce and manage pollution of any part of the environment due to all forms of human activity, and in particular from radioactive, toxic and other hazardous substances;
iii. To set targets to minimize waste generation and pollution at source and promote a hierarchy of waste management practices, namely reduction of waste at source, re-use and re-cycling, with safe disposal as the last resort;
iv. To regulate and monitor waste production, enforce waste control measures, and co-ordinate administration of integrated pollution and waste management through a single government department;
v. To set up information systems on chemical hazards and toxic releases and ensure the introduction of a system to track the transport of hazardous materials; and
vi. To ensure the protection and proactive management of health problems related to the environment in all forms of economic activity.

Nutrient (pollutant) load budgets can be determined with a low to medium level of confidence using existing data resources. While TMDLs *sensu strictu* are arguably too demanding of data and information and likely to be very costly (a situation that South Africa cannot afford), a derivative thereof, utilized as the basis of a pollutant audit for key catchments and water resources, both lotic and lentic, is clearly indicated. Equally important is the development of reservoir-specific fate of pollutants in terms of uptake, retention and discharge. The formulation of nutrient budgets would provide a logical basis on which to develop a wider understanding of the causes and consequences of, and remedial options for, eutrophication in South Africa.

5.4 Recommendations

It is recommended that the findings of this assessment form the foundation for the following:

i. Derivation of elemental export coefficients, in particular Total Phosphorus and Total Suspended Solids, for as many landuse types as possible. This process can be automated to a high degree using the National Landcover and water quality and discharge data from both currently active and inactive monitoring stations;
ii. Derivation of Desktop nutrient audits for all eutrophic and hypertrophic South African dams;
iii. Making readily available the climate (runoff) data embodied in the SA Climate Atlas;
iv. Collation of all available information pertaining to soil types and nutrient export.

It is also strongly recommended that consideration to enforce the Special Phosphorus Standard nationwide, commencing with the catchments in which eutrophic or hypertrophic dams occur. Such a move would need to proceed hand in hand with a programme of national education to explain the need. It is acceded that the above may be difficult to achieve in the absence of a national policy on eutrophication management. However, the above recommendations could serve as the nucleus of such a policy.

5.5 References

DEAT (Department of Environment Affairs and Tourism) (2000) White Paper on Integrated Pollution and Waste Management for South Africa.

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APPENDIX

APPENDIX A: EXAMPLE OF A DETAILED TMDL PHOSPHORUS RULE AND SUPPORTING WATER QUALITY CRITERIA

62-302.540 Water Quality Standards for Phosphorus Within the Everglades Protection Area.

(1) Purpose and Scope.

(a) The purpose of this rule is to implement the requirements of the Everglades Forever Act by utilizing the powers and duties granted the Department under the Act and other applicable provisions of Chapters 373 and 403, F.S., to establish water quality standards for phosphorus, including a numeric phosphorus criterion, within the EPA.

(b) The water quality standards adopted by this rule include all of the following elements:

1. A numerical interpretation of the Class III narrative nutrient criterion for phosphorus;

2. Establishment of moderating provisions for permits authorizing discharges into the EPA in compliance with water quality standards, including the numeric phosphorus criterion; and

3. A method for determining achievement of the numeric phosphorus criterion, which takes into consideration spatial and temporal variability, natural background conditions and confidence in laboratory results.

(2) Findings.

(a) The Legislature, in adopting the Everglades Forever Act, recognized that the EPA must be restored both in terms of water quantity and water quality.

(b) Best Management Practices (BMPs) have reduced phosphorus loads from the Everglades Agricultural Area to the EPA by more than twice the amount required by existing rules. Stormwater Treatment Areas (STAs) have reduced phosphorus concentrations to less than the goal of 50 ppb established in the Everglades Forever Act.

(c) While a significant percentage of the EPA currently meets the numeric phosphorus criterion, further efforts are required to achieve the criterion in the remaining impacted areas of the EPA.

(d) Even as water quality continues to improve, restoration will be a long-term process because of historic phosphorus accumulations found in sediments within impacted areas. This phosphorus can diffuse back into the water column, a phenomenon the Department recognizes as reflux.

(e) The Basin-Specific Feasibility Studies completed by the District considered environmental factors, implementation cost, scheduling, and technical factors in evaluating measures to reduce phosphorus levels entering the EPA. These studies and other information provided to the Commission show that:

1. At this time, chemical treatment technology is not cost-effective for treating discharges entering the EPA and poses the potential for adverse environmental effects.

2. Optimization of the existing STAs, in combination with BMPs, is currently the most cost-effective and environmentally preferable means to achieve further phosphorus reductions to the EPA, and to restore impacted areas. The effectiveness of such measures should be determined and maximized prior to requiring additional measures. Optimization shall take into consideration viable vegetative technologies, including Periphyton-based STAs that are found to be cost-effective and environmentally acceptable.

(f) The District and the Department recognize that STA and BMP optimization requires a sustained commitment to construct, implement, stabilize and measure phosphorus reduction benefits.

(g) The Comprehensive Everglades Restoration Plan (CERP) contains projects that will affect the flows and phosphorus levels entering the EPA. Achievement of water quality standards for water quality projects required under the Everglades Forever Act can be most effectively and efficiently attained when integrated with CERP projects.

(h) The Long-Term Plan constitutes a comprehensive program to optimize the STAs and BMPs to achieve further phosphorus reductions and thereby accomplish implementation of Best Available Phosphorus Reduction Technology (BAPRT).

(i) It is the intent of the Commission that implementation of this rule will fulfill commitments made by the State of Florida to restore and maintain water quality in the EPA, while, at the same time, fulfill the States obligations under the Settlement Agreement to achieve the long-term phosphorus concentration levels and discharge limits established in that Agreement for the Loxahatchee National Wildlife Refuge (Refuge) and the Everglades National Park (Park).

(j) Establishment of the numeric phosphorus criterion, based upon analyses conducted primarily in freshwater open water slough systems, assumed that preservation of the balance of the native flora and fauna in these open water slough systems would protect other communities of native vegetation in the EPA. Further research should be conducted in other habitat types to further evaluate the natural variability in those habitat types.

(k) The Commission has received substantial testimony regarding mercury and its impact on the EPA. The Commission encourages all interested parties to continue research efforts on the effects of mercury.

(l) The Commission finds that this rule must incorporate a flexible approach towards the application of the numeric phosphorus criterion for phosphorus in order to guide the implementation of phosphorus reductions in the Everglades Protection Area. Chapter 403, F.S., the Everglades Forever Act and U.S. Environmental Protection Agency regulations set forth at 40 CFR Part 131 include general policies that authorize such flexibility under appropriate circumstances, including those described in paragraphs (c) through (h) and (k) above. The Commission has exercised this authority by including in this rule both a numeric interpretation of the phosphorus criterion and the various other standard setting provisions of this rule, including the permitting and moderating provisions.

(3) Definitions.

(a) “Best Available Phosphorus Reduction Technology” (BAPRT) shall be as defined by Section 373.4592(2)(a), F.S. BMPs shall maintain and, where practicable, improve upon the performance of urban and agricultural source controls in reducing overall phosphorus levels. Agricultural BMPs within the Everglades Agricultural Area and the C-139 Basin shall be in accordance with Chapters 40E-61 and 40E-63, F.A.C. STA phosphorus reductions shall be improved through implementation of optimization measures as defined by Section 373.4592(2)(l), F.S. BAPRT may include measures intended to reduce phosphorus levels in discharges from a single basin or sub-basin, or a program designed to address discharges from multiple basins.

(b) “Long-Term Plan” shall be as defined by Section 373.4592(2)(j), F.S.

(c) The “Everglades Protection Area” or “EPA” shall mean Water Conservation Areas 1 (Refuge), 2A, 2B, 3A and 3B, and the Everglades National Park.

(d) “Impacted Areas” shall mean areas of the EPA where total phosphorus concentrations in the upper 10 centimeters of the soils are greater than 500 mg/kg.

(e) “District” shall mean the South Florida Water Management District.

(f) “Optimization” shall be as defined by Section 373.4592(2)(l), F.S.

(g) “Settlement Agreement” shall mean the Settlement Agreement entered in Case No. 88-1886-Civ-Hoeveler, United States District Court for the Southern District of Florida, as modified by the Omnibus Order entered in the case on April 27, 2001.

(h) “Technology-based Effluent Limitation” or “TBEL” shall be as defined in Section 373.4592(2)(p), F.S.

(i) “Unimpacted Areas” shall mean those areas which are not “Impacted Areas”.

(4) Phosphorus Criterion.

(a) The numeric phosphorus criterion for Class III waters in the EPA shall be a long-term geometric mean of 10 ppb, but shall not be lower than the natural conditions of the EPA, and shall take into account spatial and temporal variability. Achievement of the criterion shall be determined by the methods in this subsection. Exceedences of the provisions of this subsection shall not be considered deviations from the criterion if they are attributable to the full range of natural spatial and temporal variability, statistical variability inherent in sampling and testing procedures or higher natural background conditions.

(b) Water Bodies. Achievement of the phosphorus criterion for waters in the EPA shall be determined separately in impacted and unimpacted areas in each of the following water bodies: Water Conservation Areas 1, 2 and 3, and the Everglades National Park.

(c) Achievement of Criterion in Everglades National Park. Achievement of the phosphorus criterion in the Park shall be based on the methods as set forth in Appendix A of the Settlement Agreement unless the Settlement Agreement is rescinded or terminated. If the Settlement Agreement is no longer in force, achievement of the criterion shall be determined based on the method provided for the remaining EPA. For the Park, the Department shall review data from inflows into the Park at locations established pursuant to Appendix A of the Settlement Agreement and shall determine that compliance is achieved if the Department concludes that phosphorus concentration limits for inflows into the Park do not result in a violation of the limits established in Appendix A.

(d) Achievement of the Criterion in WCA-1, WCA-2 and WCA-3.

1. Achievement of the criterion in unimpacted areas in each WCA shall be determined based upon data from stations that are evenly distributed and located in freshwater open water sloughs similar to the areas from which data were obtained to derive the phosphorus criterion. Achievement of the criterion shall be determined based on data collected monthly from the network of monitoring stations in the unimpacted area. The water body will have achieved the criterion if the five year geometric mean averaged across all stations is less than or equal to 10 ppb. In order to provide protection against imbalances of aquatic flora or fauna, the following provisions must also be met:

a. The annual geometric mean averaged across all stations is less than or equal to 10 ppb for three of five years;

b. The annual geometric mean averaged across all stations is less than or equal to 11 ppb; and

c. The annual geometric mean at all individual stations is less than or equal to 15 ppb. Individual station analyses are representative of only that station.

2. Achievement of the criterion shall be determined based on data collected monthly from the network of monitoring stations in the impacted area. Impacted Areas of the water body will have achieved the criterion if the five year geometric mean averaged across all stations is less than or equal to 10 ppb. In order to provide protection against imbalances of aquatic flora or fauna, the following provisions must also be met:

a. The annual geometric mean averaged across all stations is less than or equal to 10 ppb for three of five years;

b. The annual geometric mean averaged across all stations is less than or equal to 11 ppb; and

c. The annual geometric mean at all individual stations is less than or equal to 15 ppb. Individual station analyses are representative of only that station.

If these limits are not met, no action shall be required, provided that the net improvement or hydropattern restoration provisions of subsection (6) below are met. Notwithstanding the definition of Impacted Area in subsection (3), individual stations in the network shall be deemed to be unimpacted for purposes of this rule if the five-year geometric mean is less than or equal to 10 ppb and the annual geometric mean is less than or equal to 15 ppb.

(e) Adjustment of Achievement Methods. The Department shall complete a technical review of the achievement methods set forth in this subsection at a minimum of five year intervals and will report to the ERC on changes as needed. Data will be collected as necessary at stations that are evenly distributed and representative of major natural habitat types to further define the natural spatial and temporal variability and natural background of phosphorus concentrations in the EPA. As a part of the review, the Department may propose amendments to the achievement method provisions of this rule to include:

1. A hydrologic variability algorithm in a manner similar to the Settlement Agreement; and

2. Implementing adjustment factors that take into account water body specific variability, including the effect of habitat types.

The hydrologic variability evaluation shall be based on data from at least one climatic drought cycle and data reflecting the average interior stage of the water body on the dates of sample collection.

(f) Data Screening. Data from each monitoring station shall be evaluated prior to being used for the purposes of determining achievement of the criterion. Data shall be excluded from calculations for the purpose of determining achievement of the criterion if such data:

1. Do not comply with the requirements of Chapter 62-160, F.A.C.; or

2. Are excluded through the screening protocol set forth in the *Data Quality Screening Protocol*; or

3. Were collected from sites affected by extreme events such as fire, flood, drought or hurricanes, until normal conditions are restored; or

4. Were affected by localized activities caused by temporary human or natural disturbances such as airboat traffic, authorized (permitted or exempt) restoration activities, alligator holes, or bird rookeries.

5. Were sampled in years where hydrologic conditions (e.g., rainfall amount, water levels and water deliveries) were outside the range that occurred during the period (calendar years 1978 – 2001) used to set the phosphorus criterion.

(5) Long-Term Compliance Permit Requirements for Phosphorus Discharges into the EPA.

(a) In addition to meeting all other applicable permitting criteria, an applicant must provide reasonable assurance that the discharge will comply with state water quality standards as set forth in this section.

(b) Discharges into the EPA shall be deemed in compliance with state water quality standards upon a demonstration that:

1. Phosphorus levels in the discharges will be at or below the phosphorus criterion set forth in this rule; or

2. Discharges will not cause or contribute to exceedences of the phosphorus criterion in the receiving waters, the determination of which will take into account the phosphorus in the water column that is due to reflux; or

3. Discharges will comply with moderating provisions as provided in this rule.

(c) Discharges into the Park must not result in a violation of the concentration limits established for the Park in Appendix A of the Settlement Agreement as determined through the methodology set forth in subsection (4).

(d) Discharge limits for permits allowing discharges into the EPA shall be based upon TBELs established through BAPRT and shall not require water quality based effluent limitations through 2016. Such TBELs shall be applied as effluent limitations as defined in subsection 62-302.200(10), F.A.C.

(6) Moderating Provisions. The following moderating provisions are established for discharges into or within the EPA as a part of state water quality standards applicable to the phosphorus criterion set forth in this rule:

(a) Net Improvement in Impacted Areas.

1. Until December 31, 2016, discharges into or within the EPA shall be permitted using net improvement as a moderating provision upon a demonstration by the applicant that:

a. The permittee will implement, or cause to be implemented, BAPRT, as defined by Section 373.4592(2)(a), F.S., and further provided in this section, which shall include a continued research and monitoring program designed to reduce outflow concentrations of phosphorus; and

b. The discharge is into or within an impacted area.

2. BAPRT shall use an adaptive management approach based on the best available information and data to develop and implement incremental phosphorus reduction measures with the goal of achieving the phosphorus criterion. BAPRT shall also include projects and strategies to accelerate restoration of natural conditions with regard to populations of native flora or fauna.

3. For purposes of this rule, the Long-Term Plan shall constitute BAPRT. The planning goal of the Long-Term Plan is to achieve compliance with the criterion set forth in subsection (4) of this rule. Implementation of BAPRT will result in net improvement in impacted areas of the EPA. The Initial Phase of the Long-Term Plan shall be implemented through 2016. Revisions to the Long-Term Plan shall be incorporated through an adaptive management approach including a Process Development and Engineering component to identify and implement incremental optimization measures for further phosphorus reductions.

4. The Department and the District shall propose amendments to the Long-Term Plan as science and environmental conditions warrant. The Department shall approve all amendments to the Long-Term Plan.

5. As part of the review of permit applications, the Department shall review proposed changes to the Long-Term Plan identified through the Process Development and Engineering component of the Long-Term Plan to evaluate changes necessary to comply with this rule, including the numeric phosphorus criterion. Those changes which the department deems necessary to comply with this rule, including the numeric phosphorus criterion, shall be included as conditions of the respective permit or permits for the structures associated with the particular basin or basins involved. Until December 31, 2016, such permits shall include technology-based effluent limitations consistent with the Long-Term Plan.

(b) Hydropattern Restoration. Discharges into or within unimpacted areas of the EPA shall be permitted for hydropattern restoration purposes upon a demonstration by the applicant that:

1. The discharge will be able to achieve compliance with the requirements of sub-subparagraph (6)(a)1.a. above;

2. The environmental benefits of establishing the discharge clearly outweigh the potential adverse impacts that may result in the event that phosphorus levels in the discharge exceed the criterion; and

3. The discharge complies with antidegradation requirements.

(c) Existing Moderating Provisions. Nothing in this rule shall eliminate the availability of moderating provisions that may otherwise exist as a matter of law, rule or regulation.

(7) Document Incorporated by Reference. The following document is referenced elsewhere in this section and is hereby incorporated by reference:

Data Quality Screening Protocol, dated 7-15-04.

(8) Contingencies. In the event any provision of this rule is challenged in any proceeding, the Commission shall immediately be notified. In the event any provision of this rule:

(a) Is determined to be invalid under applicable laws; or

(b) Is disapproved by the U.S. Environmental Protection Agency under the Clean Water Act, the Department shall bring the matter back before the Commission at the earliest practicable date for reconsideration.

Specific Authority 373.043, 373.4592, 403.061 FS. Law Implemented 373.016, 373.026, 373.4592, 403.021(11), 403.061, 403.201 FS. History– New 7-15-04, Amended 5-25-05.

§ 131.43 Florida.

(a) *Scope.* This section promulgates numeric criteria for nitrogen/phosphorus pollution for Class I and Class III waters in the State of Florida. This section also contains provisions for site-specific alternative criteria.

(b) *Definitions.* —(1) *Canal* means a trench, the bottom of which is normally covered by water with the upper edges of its two sides normally above water.

(2) *Clear, high-alkalinity lake* means a lake with long-term color less than or equal to 40 Platinum Cobalt Units (PCU) and Alkalinity greater than 20 mg/L $CaCO_{3.}$

(3) *Clear, low-alkalinity lake* means a lake with long-term color less than or equal to 40 PCU and alkalinity less than or equal to 20 mg/L $CaCO_{3.}$

(4) *Colored lake* means a lake with long-term color greater than 40 PCU.

(5) *Lake* means a slow-moving or standing body of freshwater that occupies an inland basin that is not a

stream, spring, or wetland.

(6) *Lakes and flowing waters* means inland surface waters that have been classified as Class I (Potable Water Supplies) or Class III (Recreation, Propagation and Maintenance of a Healthy, Well-Balanced Population of Fish and Wildlife) water bodies pursuant to Rule 62-302.400, F.A.C., excluding wetlands, and are predominantly fresh waters.

(7) *Nutrient watershed region* means an area of the State, corresponding to drainage basins and differing geological conditions affecting nutrient levels, as delineated in Table 2.

(8) *Predominantly fresh waters* means surface waters in which the chloride concentration at the surface is less than 1,500 milligrams per liter.

(9) *South Florida Region* means those areas south of Lake Okeechobee and the Caloosahatchee River watershed to the west of Lake Okeechobee and the St. Lucie watershed to the east of Lake Okeechobee.

(10) *Spring* means a site at which ground water flows through a natural opening in the ground onto the land surface or into a body of surface water.

(11) *State* means the State of Florida, whose transactions with the U.S. EPA in matters related to 40 CFR 131.43 are administered by the Secretary, or officials delegated such responsibility, of the Florida Department of Environmental Protection (FDEP), or successor agencies.

(12) *Stream* means a free-flowing, predominantly fresh surface water in a defined channel, and includes rivers, creeks, branches, canals, freshwater sloughs, and other similar water bodies.

(13) *Surface water* means water upon the surface of the earth, whether contained in bounds created naturally or artificially or diffused. Water from natural springs shall be classified as surface water when it exits from the spring onto the Earth's surface.

(c) *Criteria for Florida waters* —(1) *Criteria for lakes.* (i) The applicable criteria for chlorophyll *a*, total nitrogen (TN), and total phosphorus (TP) for lakes within each respective lake class are shown on Table 1.

Table 1

A	B	C	
Lake Color [a] and Alkalinity	**Chl-a (mg/L) [b,*]**	**TN (mg/L)**	**TP (mg/L)**
Colored Lakes [c]	0.020	1.27 [1.27-2.23]	0.05 [0.05-0.16]
Clear Lakes, High Alkalinity [d]	0.020	1.05 [1.05-1.91]	0.03 [0.03-0.09]
Clear Lakes, Low Alkalinity [e]	0.006	0.51 [0.51-0.93]	0.01 [0.01-0.03]

[a] Platinum Cobalt Units (PCU) assessed as true color free from turbidity.

[b] Chlorophyll *a* is defined as corrected chlorophyll, or the concentration of chlorophyll *a* remaining after the chlorophyll degradation product, phaeophytin *a*, has been subtracted from the uncorrected chlorophyll *a* measurement.

[c] Long-term Color > 40 Platinum Cobalt Units (PCU)

[d] Long-term Color ≤ 40 PCU and Alkalinity > 20 mg/L $CaCO_3$

[e] Long-term Color ≤ 40 PCU and Alkalinity ≤ 20 mg/L $CaCO_3$

* For a given waterbody, the annual geometric mean of chlorophyll *a*, TN or TP concentrations shall not exceed the applicable criterion concentration more than once in a three-year period.

(ii) Baseline criteria apply unless the State determines that modified criteria within the range indicated in Table 1 apply to a specific lake. Once established, modified criteria are the applicable criteria for all CWA purposes. The State may use this procedure one time for a specific lake in lieu of the site-specific alternative criteria procedure described in paragraph (e) of this section.

(A) The State may calculate modified criteria for TN and/or TP where the chlorophyll *a* criterion-magnitude as an annual geometric mean has not been exceeded and sufficient ambient monitoring data exist for chlorophyll *a* and TN and/or TP for at least the three immediately preceding years. Sufficient data include at least four measurements per year, with at least one measurement between May and September and one measurement between October and April each year.

(B) Modified criteria are calculated using data from years in which sufficient data are available to reflect maintenance of ambient conditions. Modified TN and/or TP criteria may not be greater than the higher value specified in the range of values in column C of Table 1 in paragraph (c)(1)(i) of this section. Modified TP and TN criteria may not exceed criteria applicable to streams to which a lake discharges.

(C) The State shall notify the public and maintain a record of these modified lake criteria, as well as a record supporting their derivation. The State shall notify EPA Region 4 and provide the supporting record within 30 days of determination of modified lake criteria.

(2) *Criteria for streams.* (i) The applicable instream protection value (IPV) criteria for total nitrogen (TN) and total phosphorus (TP) for streams within each respective nutrient watershed region are shown on Table 2.

Table 2

	Instream protection value criteria	
Nutrient watershed region	**TN (mg/L)***	**TP (mg/L)***
Panhandle West [a]	0.67	0.06
Panhandle East[b]	1.03	0.18
North Central[c]	1.87	0.30
West Central[d]	1.65	0.49
Peninsula[e]	1.54	0.12

Watersheds pertaining to each Nutrient Watershed Region (NWR) were based principally on the NOAA coastal, estuarine, and fluvial drainage areas with modifications to the NOAA drainage areas in the West Central and Peninsula Regions that account for unique watershed geologies. For more detailed information on regionalization and which WBIDs pertain to each NWR,*see*the Technical Support Document.

[a] Panhandle West region includes: Perdido Bay Watershed, Pensacola Bay Watershed, Choctawhatchee Bay Watershed, St. Andrew Bay Watershed, and Apalachicola Bay Watershed.

[b] Panhandle East region includes: Apalachee Bay Watershed, and Econfina/Steinhatchee Coastal Drainage Area.

[c] North Central region includes the Suwannee River Watershed.

[d] West Central region includes: Peace, Myakka, Hillsborough, Alafia, Manatee, Little Manatee River Watersheds, and small, direct Tampa Bay tributary watersheds south of the Hillsborough River Watershed.

[e] Peninsula region includes: Waccasassa Coastal Drainage Area, Withlacoochee Coastal Drainage Area, Crystal/Pithlachascotee Coastal Drainage Area, small, direct Tampa Bay tributary watersheds west of the Hillsborough River Watershed, Sarasota Bay Watershed, small, direct Charlotte Harbor tributary watersheds south of the Peace River Watershed, Caloosahatchee River Watershed, Estero Bay Watershed, Kissimmee River/Lake Okeechobee Drainage Area, Loxahatchee/St. Lucie Watershed, Indian River Watershed, Daytona/St. Augustine Coastal Drainage Area, St. John's River Watershed, Nassau Coastal Drainage Area, and St. Mary's River Watershed.

* For a given waterbody, the annual geometric mean of TN or TP concentrations shall not exceed the applicable criterion concentration more than once in a three-year period.

(ii) *Criteria for protection of downstream lakes.* (A) The applicable criteria for streams that flow into downstream lakes include both the instream criteria for total phosphorus (TP) and total nitrogen (TN) in Table 2 in paragraph (c)(2)(i) and the downstream protection value (DPV) for TP and TN derived pursuant to the provisions of this paragraph. A DPV for stream tributaries (up to the point of reaching water bodies that are not streams as defined by this rule) that flow into a downstream lake is either the allowable concentration or the allowable loading of TN and/or TP applied at the point of entry into the lake. The applicable DPV for any stream shall be determined pursuant to paragraphs (c)(2)(ii)(B), (C), or (D) of this section. Contributions from stream tributaries upstream of the point of entry location must result in attainment of the DPV at the point of entry into the lake. If the DPV is not attained at the point of entry into the lake, then the collective set of streams in the upstream watershed does not attain the DPV, which is an applicable water quality criterion for the water segments in the upstream watershed. The State or EPA may establish additional DPVs at upstream tributary locations that are consistent with attaining the DPV at the point of entry into the lake. The State or EPA also have discretion to establish DPVs to account for a larger watershed area (*i.e.*, include waters beyond the point of reaching water bodies that are not streams as defined by this rule).

(B) In instances where available data and/or resources provide for use of a scientifically defensible and protective lake-specific application of the BATHTUB model, the State or EPA may derive the DPV for TN and/or TP from use of a lake-specific application of BATHTUB. The State and EPA are authorized to use a scientifically defensible technical model other than BATHTUB upon demonstration that use of another scientifically defensible technical model would protect the lake's designated uses and meet all applicable criteria for the lake. The State or EPA may designate the wasteload and/or load allocations from a TMDL established or approved by EPA as DPV(s) if the allocations from the TMDL will protect the lake's designated uses and meet all applicable criteria for the lake.

(C) When the State or EPA has not derived a DPV for a stream pursuant to paragraph (c)(2)(ii)(B) of this section, and where the downstream lake attains the applicable chlorophyll *a* criterion and the applicable TP and/or TN criteria, then the DPV for TN and/or TP is the associated ambient instream levels of TN and/or TP at the point of entry to the lake. Degradation in water quality from the DPV pursuant to this paragraph is to be considered nonattainment of the DPV, unless the DPV is adjusted pursuant to paragraph (c)(2)(ii)(B) of this section.

(D) When the State or EPA has not derived a DPV pursuant to paragraph (c)(2)(ii)(B) of this section, and where the downstream lake does not attain applicable chlorophyll *a* criterion or the applicable TN and/or TP criteria, or has not been assessed, then the DPV for TN and/or TP is the applicable TN and/or TP criteria for the downstream lake.

(E) The State and EPA shall maintain a record of DPVs they derive based on the methods described in paragraphs (c)(2)(ii)(B) and (C) of this section, as well as a record supporting their derivation, and make such records available to the public. The State and EPA shall notify one another and provide a supporting record within 30 days of derivation of DPVs pursuant to paragraphs (c)(2)(ii)(B) or (C) of this section.

(3) *Criteria for springs.* The applicable nitrate+nitrite criterion is 0.35 mg/L as an annual geometric mean, not to be exceeded more than once in a three-year period.

(d) *Applicability.* (1) The criteria in paragraphs (c)(1) through (3) of this section apply to lakes and flowing waters, excluding flowing waters in the South Florida Region, and apply concurrently with other applicable water quality criteria, except when:

(i) State water quality standards contain criteria that are more stringent for a particular parameter and use;

(ii) The Regional Administrator determines that site-specific alternative criteria apply pursuant to the procedures in paragraph (e) of this section; or

(iii) The State adopts and EPA approves a water quality standards variance to the Class I or Class III designated use pursuant to § 131.13 that meets the applicable provisions of State law and the applicable Federal regulations at § 131.10.

(2) The criteria established in this section are subject to the State's general rules of applicability in the same way and to the same extent as are the other Federally-adopted and State-adopted numeric criteria when applied to the same use classifications.

(e) *Site-specific alternative criteria.* (1) The Regional Administrator may determine that site-specific alternative criteria shall apply to specific surface waters in lieu of the criteria established in paragraph (c) of this section. Any such determination shall be made consistent with § 131.11.

(2) To receive consideration from the Regional Administrator for a determination of site-specific alternative criteria, an entity shall submit a request that includes proposed alternative numeric criteria and supporting rationale suitable to meet the needs for a technical support document pursuant to paragraph (e)(3) of this section. The entity shall provide the State a copy of all materials submitted to EPA, at the time of submittal to EPA, to facilitate the State providing comments to EPA. Site-specific alternative criteria may be based on one or more of the following approaches.

(i) Replicate the process for developing the stream criteria in paragraph (c)(2)(i) of this section.

(ii) Replicate the process for developing the lake criteria in paragraph (c)(1) of this section.

(iii) Conduct a biological, chemical, and physical assessment of waterbody conditions.

(iv) Use another scientifically defensible approach protective of the designated use.

(3) For any determination made under paragraph (e)(1) of this section, the Regional Administrator shall, prior to making such a determination, provide for public notice and comment on a proposed determination. For any such proposed determination, the Regional Administrator shall prepare and make available to the public a

technical support document addressing the specific surface waters affected and the justification for each proposed determination. This document shall be made available to the public no later than the date of public notice issuance.

(4) The Regional Administrator shall maintain and make available to the public an updated list of determinations made pursuant to paragraph (e)(1) of this section as well as the technical support documents for each determination.

(5) Nothing in this paragraph (e) shall limit the Administrator's authority to modify the criteria in paragraph (c) of this section through rulemaking.

(f) *Effective date.* This section is effective on January 6, 2013, except for § 131.43(e), which is effective February 4, 2011.

[75 FR 75805, Dec. 6, 2010, as amended at 77 FR 39951, July 6, 2012]