Review of Research Projects and Program Direction for the South African Water Research Commission

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Photos Courtesy of B. Usher
Review of Research Projects and Program Direction for the Water Research Commission

Executive Summary

In July and August of 2005 the Water Research Commission (WRC) instituted an external review of three specific research projects which they have funded, and of the overall research program directions in groundwater studies at the WRC. The specific projects all involved topics of groundwater contamination. The three research projects evaluated were:

- Identification and Prioritization of Groundwater Contaminants and Sources in South Africa’s Urban Catchments – Usher et al., 2004
- Field Investigations to Study the Fate and Transport of DNAPLs in Groundwater – Usher et al.
- Improved Methods for Aquifer Vulnerability Assessments Producing Vulnerability Maps, Taking into Account Information on Soils – Campbell, Fey et al.

The overall research program direction was to be evaluated considering previously funded research topics, the procedures in place for project selection and review, and the guidance given in Sililo et al., 2001 which was a project funded through WRC to evaluate research objectives of the Commission.

Summary of Reviews for Specific WRC Projects

1. Identification and Prioritization of Groundwater Contaminants and Sources in South Africa’s Urban Catchments – Usher et al., 2004.

This project, as the name implies, explored the contaminants issuing from South Africa’s urban areas, and evaluated and ranked chemical parameters associated with risk. As part of this review, the University of the Free State, Institute for Groundwater Studies was visited and discussions were held on the first two projects over the course of a week and a half. This first evaluated research project was the only completed undertaking in the external review of specific research – the other two research efforts under review were ongoing.

Analysis: This project and the subsequent final report are solid contributions to science and the management of South Africa’s water quality challenges in urban catchments. Some of the challenges faced by the research team underline the difficulty in obtaining water related information in South Africa. The project supported students and provided capacity building. There are minor errors in the risk assessment portion of the project.
Recommendation: Because of the potential utility of the risk assessment, it is recommended that the package be regularly updated, distributed, and educational training on its use be scheduled with potential users.

2. Field Investigations to Study the Fate and Transport of DNAPLs in Groundwater – Usher et al.

This ongoing project is attempting to characterize the movement and transformation of Dense Non Aqueous Liquids (DNAPLs) with particular reference to South African geology and conditions. The two field sites associated with this research were visited, borehole television was reviewed, faculty and students associated with this project were interviewed, and supporting laboratories and associated experiments were observed.

Assessment: This is a well-conceived project, with the potential for a strong contribution to not only South Africa, but the larger scientific community as well. The interim project reports are well documented and show an excellent literature search has been carried out. The inclusion of students in the project has been superb, mentorship first-rate. Despite challenges typical of this sort of research, the work is proceeding well.

Recommendations: Specific recommendations include the continuing of efforts to obtain another flagship site if possible, investigation of the effect of borehole construction on research results, consideration of the use of environmental tracers, modification and refinement of laboratory studies, more testing of varied field screening methodologies, and evaluation of the drawbacks in modeling packages and analytical techniques designed for porous media in fractured rock aquifers.

3. Improved Methods for Aquifer Vulnerability Assessments Producing Vulnerability Maps, Taking into Account Information on Soils – Campbell, Fey et al.

This project has an aim of testing methodologies and evaluating protocols for the mapping of aquifer vulnerability in South Africa. A diverse team of scientists has been put together to view the attenuation properties of the soil, vadose zone, and aquifers. The team epitomizes the idea of approaching the problem in an interdisciplinary way, and the group has a variety of experience. Field sites for this project include a site in the Cape Flats aquifer, and the Secunda site. The approaches for assessing groundwater vulnerability include evaluating the utility of the DRASTIC and UGIF codes to help predict attenuation properties without specific drilling and sampling.

Assessment: This also is a well-conceived project, and has great potential benefit to groundwater managers, provided it is not misused by them. The research is 60-70% complete. The literature surveys are done, soils testing is near completion, modeling efforts are moving along, and the GIS base for incorporation of mapping is good. There has been a fair amount of personnel turnover on this project, including attrition of the
students employed on this project, thus reducing the amount of capacity building which is desirable for all WRC projects.

Recommendations: It is recommended that student involvement and capacity building be an important focus in the remaining project effort. The disparate elements of the interdisciplinary team have performed well on the parts of the project; it is crucial to the eventual success of the project to now integrate and share information. Vulnerability of groundwater to organic contamination has not been a large focus of the project – more emphasis should be given to these compounds and Non Aqueous Phase Liquids (NAPLs), either in this or a later project. In order to expand the applicability of this study, comparison with other international work should be carried out both with laboratory experiments (e.g. attenuation capacity of soils), and in field experiments (e.g. analogies and differences in the Cape Flats Aquifer and other highly studied aquifers such as the Borden Landfill in Canada). Results from this study should be used in the risk analysis in Project One above. Perhaps most importantly, the reporting of uncertainty and variability in vulnerability predictions should be prominently included in the final report. This would ensure that managers and other users of this report understand the limitations and the possible range of groundwater vulnerability possible. Because this research is an evaluation of specific methodologies and the value of vulnerability predictions in a South African context, any associated uncertainty will be a crucial factor in determining the efficacy of those vulnerability predictions.

Summary of Review of the Overall WRC Program Direction in Groundwater

A review of the past and current WRC research directions was carried out, including a brief review of procedures for grant selection and administration, past and current research directions, and suggestions for possible future areas of investigation. Generally project administration appears to be very good. The WRC research proposal review is rigorous, the ongoing projects are reviewed regularly by an outside panel, and the final reports are subject to review as well. WRC is rightly promoting a culture of rigorous research proposal preparation and should continue to do so – these documents should be state-of-the-science. The current and past projects blend a variety of research areas, disciplines, and approaches, resulting in a balanced research program. Also the research efforts are spread among many public institutions and some private entities. This balance also allows for more students from more backgrounds to be involved in WRC funded research and promotes capacity building. While many projects have great benefit to localities, many attempt to address national issues as well.

More specific suggestions for future research includes:

1. Specific Follow-on to the Projects Discussed Above.
   a. Non Aqueous Phase Liquids (NAPLs)
   b. Rapid detection of Microorganisms
   c. Lack of Data Pesticides - Pesticide Field scale fate and transport
   d. High nitrate
5. The Scientific, Engineering, and Legal Basis to Expand Early Action and Interim Remediation at Contaminated Sites.
6. Addressing the Challenge of Small Waste Generators.
7. Developing Concentration Based Action levels.
8. Regulatory Coordination Aspects.
12. Surface - Groundwater Interactions and the Hyporheic Zone.
15. Expanding Training.
16. Establishing and Strengthening International Partnerships

Overall, the scaling differences are formidable between laboratory work, field studies in specific locales, and projects attempting to give national guidance. These different aspects should be all considered in WRC’s research approach. These diverse scales of research should all be continued and supported. The research program should also continue to bridge the gap between unique projects of local importance and conditions, and overarching national applications and management in South Africa.
Review of Research Projects and Program Direction  
for the Water Research Commission

Introduction

This report details findings of an external research review, conducted by Dr. David Kreamer, University of Nevada, for the Water Research Commission (WRC), government of the Republic of South Africa. In July and August of 2005 the WRC instituted this review of three specific research projects which they have funded, and of the overall research program directions in groundwater studies, particularly groundwater contamination studies at the WRC. The projects reviewed all involved topics of groundwater contamination. The three research projects evaluated were:

- Identification and Prioritization of Groundwater Contaminants and Sources in South Africa’s Urban Catchments – Usher et al., 2004
- Field Investigations to Study the Fate and Transport of DNAPLs in Groundwater – Usher et al.
- Improved Methods for Aquifer Vulnerability Assessments Producing Vulnerability Maps, Taking into Account Information on Soils – Campbell, Fey et al.

As part of this review, the home universities and agencies conducting the research were visited, field sites associated with this research were inspected, and project proposals and interim reports and final reports were reviewed when available. The modeling approaches proposed in the various projects were evaluated, developed software was examined, supporting laboratories and associated experiments were observed, and faculty, staff, and students associated with these and other projects were interviewed.

Several factors were used to evaluate the overall research direction of WRC groundwater studies. These factors included the procedures in place for project selection and review, the past history of previously funded research topics, and the guidance given in Sililo et al., 2001 which was a project funded through WRC to evaluate research directions of the Commission. Procedures for project selection and review were discussed with Dr. Kevin Peitersen of the WRC, and documentation of WRC goals, procedures and projects were reviewed. The documentation included detailed synopses of recent WRC projects, providing an overview of recent and ongoing work. Sililo et al., 2001 was provided and reviewed, with an eye toward evaluating its present relevance.
Reviews for Specific WRC Projects

1. **Identification and Prioritization of Groundwater Contaminants and Sources in South Africa’s Urban Catchments – Usher et al., 2004.**

   This project, as the name implies, explored the contaminants issuing from South Africa’s urban areas, and evaluated and ranked chemical parameters associated with risk. Contaminants were prioritized nationally and for different provinces as well. A risk analysis module was put together as part of the final report for this research. As part of this review, the University of the Free State, Institute for Groundwater Studies was visited and discussions were held on the first two projects over the course of a week and a half. This research project was completed in July of 2004. The final report has two parts. Part one lists the findings of surveys of inorganic and organic contaminants and associated sources in South Africa’s urban catchments, and part two provides guidelines for assessing and evaluating the impacts of human activities on groundwater resources.

   As part of this research many sources for groundwater quality data were investigated. It was noted that there were significant hurdles to data collection. Particularly, the researchers found that most organizations, including the South African Department of Water and Forestry collect surface water data, but few groundwater analyses were available. The study developed an excel-based data information system in which contaminants, associated sources, and contaminant properties are stored. A national inventory was conducted to determine which pollutants exist in South African groundwater. A source and contaminant prioritization list was then established for South Africa, Gauteng, Durban, Cape Town, and Port Elizabeth. A tier-based risk approach for prioritization was developed as a tool to rank the magnitude of groundwater pollution problems in urban environments.

Review of Findings to Date and Project Analysis.

This project and the subsequent final report are solid contributions to science and the management of South Africa’s water quality challenges in urban catchments. The excel-based listing developed in the course of this project is an excellent start to capturing the extent of the groundwater quality problems in urban catchments. Some of the challenges faced by the research team underline the difficulty in obtaining water related information in South Africa. The lack of available data, and lack of compatible, electronic, Geographical Information System (GIS) based information systems for groundwater, constitutes a significant problem in the advancement of groundwater research, informed policy development, and future planning for this resource in South Africa. At a minimum the WRC should standardize its data reporting format for all its projects. In a larger sense, the WRC should seek to assist the diverse government agencies and private companies and consults in working toward a common, robust, versatile, electronically-based, and GIS compatible data base. The project supported students and provided capacity building.

The risk assessment portion of this report is a strong contribution, and should have broad applicability throughout the country and surrounding nations, even beyond
urban catchments. It should be noted that there are minor errors in this risk assessment portion of the project. For example, some contaminants are listed twice, under different names, with different rankings, slightly different attributes and health risk. These errors should be addressed in updated versions of the tier-based risk assessment.

Recommendation.

Generally the researchers are to be commended for an extremely useful study, which establishes baseline information which can be used for initial water quality planning, future research, and human welfare assessment. Because of the potential utility of the risk assessment, it is recommended that the package be regularly updated, distributed, and educational training on its use be scheduled with potential users.

2. Field Investigations to Study the Fate and Transport of DNAPLs in Groundwater – Usher et al.

This ongoing project is attempting to characterize the movement and transformation of Dense Non Aqueous Liquids (DNAPLs) with particular reference to South African geology and conditions. The project assesses the distribution, fate and transport of DNAPLs through a series of field and laboratory investigations. The project also tests different field screening methodologies, and geophysical techniques. As part of this review, the two field sites associated with this research were visited, borehole television was reviewed, faculty and students associated with this project were interviewed, and supporting laboratories and associated experiments were observed.

The University monitoring well field is a highly instrumented field site with about as good field control as could be expected in a fractured rock environment, while the railroad/gas works site (Test Site One) has the complexities of a real site investigation faced by regulators and consultants. Therefore, a good balance is achieved between a simpler, pilot-type field investigation, and a large, uncontrolled field trial situation.

Gasworks construction at research Site One in 1980 (courtesy of B. Usher and Research Site One).
The geologic differences, contaminant complexities, and system monitoring well differences in the field locations embodies a good blend of site complexity and control, near the ends of the spectrum of possible field investigation. The researchers have investigated the possibility of a third research field site. While this is a possibility, and it would be good to have a third research area, (a contaminated site which is a middle case between the two current sites perhaps with only a single parent compound contaminant), the resource and time limits on this research may make it infeasible.

Review of Findings to Date and Project Analysis.
This is a well-conceived project, with the potential for a strong contribution to not only South Africa, but the larger scientific community as well. The interim project reports are well documented and show an excellent literature search has been carried out. The inclusion of students in the project has been superb, mentorship first-rate. Laboratory approaches have been modified to maximize benefit, and wettability studies have begun to quantify physical properties applicable to transport studies. The investigators should continue to look for a third flagship field site, but the research can produce useful results even if no third site is identified. Despite challenges typical of this sort of research, the work is proceeding well.

Recent borehole geophysical work and television logs, have opened up the possibility of comparing viewed features (fractures etc.) with various geophysical techniques, salinity profiles, borehole construction details, and hydrologic analysis. Cross-hole analysis can now be implemented and 3-dimension fracture patterns in the hard rock aquifer can be mapped. The existence of, or lack of, correlation of logged parameters to observed features will allow independent evaluation of many factors crucial to DNAPL movement and distribution. Another benefit of this increased geologic and hydrogeologic definition will be the ability to evaluate modeling and data analysis approaches. Many of the modeling methods used in this study (e.g. MODFLOW) and data analysis techniques (e.g. Jacob-Cooper drawdown analysis and FC methods) were originally developed and intended for porous media, but are modified for fractured rock media in this study. In the initial proposals, several modeling approaches were listed for possible investigation. However, codes such as the TOUGH code might be hard to populate and the addition of these codes for analysis may not reap great benefits.
The use of environmental tracers, for example stable isotopic analysis or tritium measurement, is dismissed by the researchers in an interim report for this study on the basis of a statement in a past Ph.D. dissertation. This is inconsistent with the demonstrated value of these techniques at some specific sites. The interpretation of environmental tracers is underused in subsurface contamination studies generally, but can be a powerful tool. The railroad/ gasworks Test Site One is, in some ways, a good site to evaluate the potential utility of a suite of environmental tracers. If environmental tracers are not evaluated in this study, a follow-on study should be considered. Likewise, the potential use of carbon or chlorine isotopic ratios for forensic analysis of the subsurface solvent concentrations is promising and bears testing in this, or a similar study.

Pictures from Test Site One – July 2005
A statement was made in an interim report by the researchers that a single finding of dichloroethene (DCE) in a single borehole at Test Site One is evidence that natural degradation is occurring. This is probably a premature statement, and a more complete strategy to determine the biological and the chemical transformation properties and potential at Test Site One is in order. The possibility of using BIOCHLOR or some other modeling approach to buttress transformation interpretations is an option left open by the researchers; like many proposals in research projects generally, it is difficult to assess whether this would be worthwhile, before such modeling is carried out. It is also therefore difficult to predetermine whether resources focused on such modeling could be better utilized elsewhere.

A good start has been made in quick screening methods with the fluorescence testing done at the site. The suitability of other rapid screening methods, such as immunological surveys, should be ascertained.

Recommendations.

Specific recommendations for the DNAPL project include the continuing of efforts to obtain another flagship site if possible. However, another site, while desirable, is not necessary for the project to make significant contributions. Rather than devote resources to a new site, perhaps focusing on testing more methodologies on existing research sites would be appropriate. Cross-borehole analysis based on recent downhole logging will help solidify geologic and hydrologic interpretations, and indicate relative efficacy of surface geophysical techniques. Television logs should be studied to begin to ascertain whether borehole construction might influence research results. As mentioned above, consideration of the testing of environmental tracers is important in the overall research planning, although might be deemed more appropriate for a future project. It is recommended that more testing of varied field screening methodologies be undertaken to add value to the successful investigations done so far. Re-evaluation of the relevance of modeling packages and analytical techniques designed for porous media, but used in fractured rock aquifers, would provide helpful insights for future researchers.


In this research study, a multidisciplinary team is testing methodologies and evaluating protocols for the mapping of aquifer vulnerability in South Africa. The major thrust of these researchers is to assess naturally-occurring attenuation mechanisms in the soil, vadose zone, and groundwater zone, and test methods of summarizing that information in a geographical information system context. Vulnerability is defined by the team as “The sensitivity to contamination, determined by the natural intrinsic characteristics of the geologic strata forming the overlying confining beds or vadose zone of the aquifer concerned” (Foster et al., 2003) and “The tendency…for contaminants to reach a specified position in the groundwater system after introduction at some location” (NRC, 1993). The team views the ease with which groundwater may become
contaminated as being in part “controlled by the nature of the strata overlying the aquifer, climatic conditions, and the nature of the contaminant or contaminant mixture.” In the saturated zone vulnerability is defined as a function of the persistence in time and the spatial extent of contamination.

The diverse team of scientists put together to quantify and model contaminant attenuation exemplifies the idea of approaching the problem in an interdisciplinary way, and the group has a variety of experience. Field sites for this project include a site in the Cape Flats aquifer, and the Secunda site, illustrated below. These sites are inorganic contamination sites.

The approaches for assessing groundwater vulnerability include evaluating the utility of the DRASTIC and UGIF codes to help predict attenuation properties without specific drilling and sampling.

In order to assess the attenuation properties of South African soils horizons, sorption studies were undertaken. In previous reports, the sorption of copper, Cu (representing metal cations) and phosphorus, P (representing anions) for 72 soil materials was detailed. As an example, the sorption result for 13 of the 72 soils is shown below for copper.
The soils research is also attempting to relate soil properties, such as clay content, cation exchange capacity, iron content, pH, aluminum content, exchangeable bases, and organic content to sorption. The study is now continuing measuring copper and phosphate sorption with approximately 200 soils, testing a subset of these soils with a second metal (zinc, Zn) and a second anion (sulphate, SO\textsubscript{4}\textsuperscript{2-}), evaluating the descriptive power of sorption tests for diagnostic South African horizons, and refining the predictive capacity of inferred soil attenuation rankings. Vulnerability classification of the soil will be based on a 1 to 5 scale rankings for both hydraulic attenuation and for chemical attenuation. For use in sorption experiments, the soils group has accessed archived soil samples from around South Africa which are well-defined and studied.

In vadose zone analysis, the objectives include identifying the most important factors affecting vulnerability. These factors are specified by the researchers as hydraulic properties of the unsaturated zone, thickness of the unsaturated zone, flow mechanisms, drainage/recharge, travel time, sorption capacity, and contaminant half-lives. Hydraulic characterization of the vadose zone will center on defining matrix vs. preferential flow. To establish the effects of fractures/macropores on contaminant transport, chloride solute profiling in the unsaturated zone will be used to identify dominant (matrix and/or preferential) flow patterns. Vadose zone geology/geomorphology will be inferred from borehole logs and lithologies but will be non-quantitative. The team of researchers investigating attenuation of the unsaturated zone will work to improve and test vadose zone transport models. The prediction of properties without extensive drilling and sampling programs requires viewing existing databases and using prediction tools such as the codes RETC and Rosetta. Numerical models will be used to help identify matrix and preferential flow patterns, and must be calibrated. Models considered for vadose zone simulation included VLEACH, MACRO 5.0 (can handle macropore flow in soils), HYDRUS 2D, SWMS 2D, SWAT, SWAP (which can handle preferential flow in cracking/swelling clays), and UGPF (a GIS based model which can analyze organic compound degradation). HYDRUS 2D and SWMS 2D are likely candidates for initial work. Sensitivity analyses will comprise an important component of the work.

The objective of the groundwater zone component of this study is to develop methods for assessing saturated zone processes that affect aquifer vulnerability. The research approach assumes that the probable lifetime of aquifer contamination is determined by factors such as effective flow rate, geochemical buffering and decomposition, and recharge. The saturated zone’s contribution to vulnerability will be estimated by predicting the persistence and spatial extent of groundwater contamination. This will be done using a one-dimensional solute transport model for priority sources and contaminants, a flow and transport model for case study sites (for inorganic contaminants), and modeling degradable organic contaminants. Multi-component fate and transport modeling will require consideration of retardation factors and a model such as PHREEQC(2) will simulate one-dimensional reactive transport, and equilibrium and kinetic chemistry. Use of these models will simulate the chemical evolution of groundwater and to establish reasonable geochemical parameters for vulnerability assessment. This reactive transport modeling of contaminant mixtures in South African aquifers will seek to predict the travel distance of a contaminant front from its source in
each aquifer in a fixed time (assuming various conditions such as continuous leakage, pulsed sources, flushing events, various degradation rates of contaminants). Different aquifer material and different contaminant mixtures will be simulated, and followed with the use of groundwater flow models to refine the vulnerability estimates based on best available information on piezometry, hydraulic characteristics, extent of heterogeneity, and recharge and discharge, assuming conservative, non-reactive transport. It is planned that groundwater modeling will be demonstrated at the Secunda and Cape Flats field sites. The original plan called for testing of organic and NAPL movement.

The integration of these different vulnerability studies will be linked in order to model site specific soils, contaminants, vadose zone environments, and groundwater conditions. The goal of this integration of the results from various zones is to improve GIS-based methods utilizing UGIF and DRASTIC, and develop new GIS based algorithms for vulnerability assessment. The usability of DRASTIC will be enhanced by developing an easy-to-use interface, with theoretical enhancement of the layered index approach. The modified DRASTIC approach to intrinsic vulnerability will be tested at study sites. Uncertainty and confidence levels will be taken into account, and guidelines and decision support will be produced for assessing vulnerability and producing vulnerability maps. The output will embody a revised approach for assessing aquifer vulnerability under South African conditions, will produce special-purpose classification of South African soils, improve aquifer vulnerability assessment methods, produce guidelines for developing specific vulnerability maps, and result in a short course on “Vulnerability Assessment and Mapping”.

Review of Findings to Date and Project Analysis

This is a well-conceived project, and has great potential benefit to groundwater managers, provided it is not misused by them. The research is 60-70% complete. The literature surveys are done, soils testing is near completion, modeling efforts are moving along, and the GIS base for incorporation of mapping is good. The disparate elements of the interdisciplinary team have performed well on the parts of the project; it is crucial to the eventual success of the project to now integrate and share information. There has been a fair amount of personnel turnover on this project, including attrition of the students employed on this project, thus reducing the amount of capacity building which is desirable for all WRC projects.

In the soils portion of the project, a sizable amount of research effort has gone forward to identify the sorptive properties of many South African soils. This is solid, fundamental work, which is clearly in line with project objectives. By the very nature of the research, representative chemical species and soils had to be selected for testing. The soils selection relies on archived soil samples from around South Africa, which is a large, robust, potential resource and database to support sorption testing. Less broad is the variety of chemicals being tested – only four types of inorganic compounds. It is not clear how representative the compounds chosen for soils sorption testing are compared to the universe of actual contaminants existing in South African soils, particularly those compounds prioritized in Usher et al 2004, Identification and Prioritization of Groundwater Contaminants and Sources in South Africa’s Urban Catchments. Organic
compounds are not addressed, and the range of possible metals speciation due to eH-pH variations in the soil is not well constrained. This limits the broad applicability of the results of sorption testing. The researchers recognize that aquifer vulnerability is “controlled by the nature of the strata overlying the aquifer, climatic conditions, and the nature of the contaminant or contaminant mixture,” eventual research should broadly address all of these areas. Of these areas, the present project strengths are in defining the nature of the strata overlying the aquifer and climatic conditions.

The researchers also observed that the “more preferential flow dominates, the less important chemical attenuation becomes, and vice versa”. The levels of uncertainty in estimates of preferential flow are not entirely clear, for this study. Nor is the prevalence and variability of preferential flow well defined in the target South African soils, vadose zone environments, and aquifer systems. The link between controlled laboratory testing for flow parameters, and utilization of measured parameters in modelling efforts, needs to be plainly apparent – for example, it is not entirely clear whether vadose zone flow estimates will be predicated on chlorine movement studies, controlled laboratory tests, or some combination of these and other factors. In some modelling efforts, parameters populating the models could be better buttressed with coordinated laboratory and field measurement. The horizontal versus vertical hydraulic conductivity ratio (Kh/Kv) for instance, is a parameter which will be incorporated into some transport modelling, but which is not being comprehensively measured. It should be noted that questions of varying scale are significant challenges to the modelling effort, and should be investigated further, if not in this research study, in following work.

In some modelling efforts for this project, sorption will be incorporated using retardation factors which mathematically assume linear sorption isotherms. The challenge with assuming linear sorption isotherms is that nature doesn’t always exhibit linear isotherms, particularly when a large flush of pollutants uses up available sorption sites on soils and vadose zone material. The assumption of linearity is therefore non-conservative, and will over-predict attenuation capacity, which is not precautionary. Contaminant degradation is mostly modelled in this project using first-order rate kinetics (half-life). Unfortunately, not all degradation processes follow this type of transformation, and can be of different order. Likewise, a generally adopted definition of vulnerability by this group of researchers is the “tendency… for contaminants to reach a specified position in the groundwater system after introduction at some location” (NRC, 1993)” (my emphasis). The attendant non conservative assumption is made that no harmful daughter products can be generated after the parent is introduced. This non conservative assumption ignores the possibility that harmful daughter products or contaminant species can be generated, and the assumption is non precautionary.

Ultimately, sensitivity analysis is planned to be done which will be an important feature of this modelling, as will be evaluation of parameter uncertainty. The field parameters can vary widely as seen in unpublished data for soil parameter measurement below. The uncertainties in the parameters used to populate the models, therefore, need to be addressed for the end-users and managers of this research product.
Sample Number Required to Estimate Various Soil, Water, and Chemical Transport Properties to Within 10, 20, and 50% of the Mean Value at 95% Confidence Interval

(W. Jury)

<table>
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The research team states that the integration of these different vulnerability studies will be linked using case studies to model site specific soils, contaminants, vadose zone environments, and groundwater conditions. The case studies should move forward soon in order to meet project goals. The GIS and mapping component work has a good start, with the framework already designed. It is crucially important at this juncture to integrate the various team efforts from the different parts of the project, in a way that gives proper weight to factors affecting vulnerability. This integration is not comprehensive at this time. Details can be improved in integrated approaches as well, for example rainfall estimation currently used in the modeling can be made more robust by including an area-elevation adjustment to measured rainfall values used as model inputs. In another example, it is unclear how the results from the limited number of contaminants measured in laboratory attenuation studies will be broadly applied to the variety of pollutants possible at the selected field sites. It is also unclear how surface - groundwater interactions will be treated, particularly the vulnerability of the hyporheic zone. Areas in South Africa with massive subsidence and with the potential for substantial collapse will be areas of great exception to typical vulnerability estimates, and must be treated separately. How these exceptional areas will be treated is currently not unequivocally defined. For illustration, below is an aerial photograph of a large subsidence feature in the Gauteng Province.

Photo courtesy of JMA consultants
Recommendations.

It is recommended that student involvement and capacity building be an important focus in the remaining project effort. Vulnerability of groundwater to organic contamination has not been a large focus of the project – more emphasis should be given to these compounds and Non Aqueous Phase Liquids (NAPLs), either in this or a later project. In order to expand the applicability of this study, comparison with other international work should be carried out both with laboratory experiments (e.g. attenuation capacity of soils), and in field experiments (e.g. analogies and differences in the Cape Flats Aquifer and other highly studied aquifers such as the Borden Landfill in Canada). In the soils research attempting to relate soil properties, such as clay content, cation exchange capacity, iron content, pH, aluminum content, exchangeable bases, and organic content to sorption, multivariate statistics could be employed to determine if some properties act in concert.

Results from this study should be used in the risk analysis in Project One above. Perhaps most importantly, the reporting of uncertainty and variability in vulnerability predictions should be prominently included in the final report. This would ensure that managers and other users of this report understand the limitations and the possible range of groundwater vulnerability possible. Because this research is an evaluation of specific methodologies and the value of vulnerability predictions in a South African context, any associated uncertainty will be a crucial factor in determining the efficacy of those vulnerability predictions. Finally, the researchers planned to give at least one short course on the results of this research. With the large potential utility of the research findings of this work, several presentations, short courses, and training seminars should be planned to disseminate the findings.

Comments on the Future Research Directions of the Water Research Commission Program

Introduction

The research funded by the Water Research Commission (WRC) was evaluated, with particular attention to future directions for research in groundwater and water management. The following recommendations were developed to address potential topics of importance in upcoming research efforts. Many of the suggestions are issues already planned for future work, are impending projects, or are subject areas with work already in progress, however, some are new areas of focus for research effort. The following are suggested themes for future research, based on this review.

1. Project Follow-on for the Specific Research Reviewed in this Report.

One set of recommendations are for specific follow-on work for the three projects reviewed in this external review and assessment. The suggested follow-on specifically involves: a. updating risk assessment in urban catchment pollution prioritization study (Usher 2004), b. incorporating vulnerability findings (CSIR) into that risk assessment, c. studying aquifer vulnerability to organic chemicals and NAPLs, and d. a Light Non
Aqueous Phase Liquid (LNAPL) study to follow up the DNAPL study, including investigating LNAPL movement and uniform procedures for petroleum service station monitoring.

The risk assessment in Usher et al., (2004) has a great potential for broad application and utility after it is updated and minor errors are corrected. The findings of the ongoing vulnerability study will be a natural fit into that risk assessment program, and expand its applicability and the eventual use of both research projects. A definite need is to add the whole realm of organic chemicals and NAPLs to the present vulnerability study. This is an area of pressing concern for South Africa. Likewise, a LNAPL study is a natural extension and companion study to the ongoing DNAPL research project, and has great importance to national challenges.

2. Addressing Specific Areas of Concern noted by Usher et al. (2004).

Usher et al., (2004) reported specific areas of concern after their study on urban catchments. They noted as mentioned above, Non Aqueous Phase Liquids (NAPLs) are types of pollutants where not enough basic information is available on amounts used and spilled, utilization and wastage, and distribution in natural environments. That observation is extended to a more encompassing recommendation that all organic compounds, even those that are not NAPLs, be given much more attention in South African contamination research. Historically, these compounds have been not consistently measured, have been under-reported, and in some cases have been ignored in field investigations. Even in regulatory guidance, little has been said about organic chemical contamination of water. For example, the following is guidance provided by the Department of Water Affairs and Forestry (DWAF) shows the minimum monitoring requirements for indicator analyses of water. The guidance chart below doesn’t give any weight to organic pollutants. Organics are notable due to their absence. The guidance states, “Analysis for unknown organic compounds is very difficult, because of the vast range of constituents which may be present. The use of GC (gas chromatograph) equipment for routine analysis of waste is therefore not feasible” (DWAF, Minimum Requirements for Water Monitoring at Waste Management Facilities). It should be noted that as of this review, these minimum requirements were being revised.

![Diagram of Minimum Monitoring Requirements for Indicator Analyses](image_url)
Usher et al. also made recommendations promoting the rapid detection of microorganisms. They noted the lack of data pesticides, and the paucity of pesticide field scale fate and transport evaluation. Not only are pesticides a concern in and of themselves, but in the past they have often been mixed with solvents and other potential contaminants before application. Lastly, Usher et al. (2004) noted the potential problems with high nitrate in South Africa, particularly resulting from fertilizer use, pit latrines, and explosives production. More research in this area would be appropriate.


It is also proposed that a new research could investigate links between effective groundwater remediation and proper site characterization. This would also underline the necessity for links between well-directed engineering and strong interdisciplinary science. Specifically, the potential topics would include the hydrogeologic factors, contaminant factors, and system design factors affecting remediation and site assessment in a South African context.

Hydrogeologic factors that affect remediation and assessment include subsurface heterogeneity (particularly the effect of low permeability layers, and dikes and sills), fractured or karst aquifers, and other complexities. The interaction of these physical features in the subsurface with contaminant migration and distribution can dominate the eventual efficacy of remediation. The best ways to determine these complexities in the field and appropriately adjust remediation is rarely clear, and represents a challenging area for future research.

Contaminant factors that affect remediation and assessment include mixed waste, continued leaching from source areas, partitioning between groundwater and aquifer solids, the presence of non aqueous phase liquids, and other factors. Research in some of these areas (e.g. sorption) has already begun. Many waste streams in South Africa are not simple and the complex nature of these contaminant sources provide a hurdle to proper site cleanup. Work is needed in this area.

System design factors affecting remediation and assessment are varied. As the well drilling options in South Africa expand, there is a need to define the most advantageous drilling techniques and future drilling technologies. Guidance needs to be developed for optimally locating remedial extraction wells, and on efficient pumping schemes in a national context. It is also important to identify the potential for unplanned, negative consequences of remedial actions in South Africa.

In this last category of system design, one of the most important needs for help, guidance, and research is in the area of monitoring well design. Many monitoring systems in South Africa exhibit poor well design, by poor selection of screening depths, lack of nested wells, and inappropriate well material. The frequency of sampling is also not optimized. Precautions in well drilling and placement are often not considered (such as an outside-in progression in well placement). Research and national guidance is needed in all these areas.
Another system design topic appropriate for study in South Africa is determining the proper number of monitoring wells at individual sites. Geometrically it takes a minimum of three boreholes to determine groundwater direction from head elevation. The guidance document, “Minimum requirements for Water Monitoring at Waste Management Facilities” (DWAF), however does not require this bare minimum. Of the 26 listed categories of potential contaminant facilities, 12 require less than 3 boreholes, and in some categories the minimum number of boreholes is zero (e.g. pit latrines and septic tanks). Perhaps the assumption is that groundwater follows the topographic gradient, but if that is the case, a comprehensive survey should determine how often this assumption is likely to be correct. Factors that influence the proper interval between downgradient monitoring wells (and therefore number of wells) at any particular site include: 1. whether the geology is complicated or simple, 2. if there are closely spaced fractures, faults, tight folds, solution channels, discontinuous structures versus absence of those features, 3. whether the aquifer material is heterogeneous or homogeneous, 4. if hydraulic conductivity is variable or constant, 5. if lithology is variable or uniform, 6. if the aquifer if located near a recharge zone, 7. whether the hydraulic gradient is steep and/or variable versus flat and/or constant, 8. if the dispersivity potential is high or low, and 9. if flow velocity in the boreholes is high or low.


Early warning, leak detection, screening, tracers, and other methods could remove the need for remediation and save millions of rand, yet South Africa has not yet invested in these technologies extensively. Determining the efficacy of these technologies and their applications requires an interdisciplinary research approach. Some of the methodologies include the use of tracers, fiber optic devices, immunological surveys, fluorescence techniques, soil gas surveys, dye techniques, direct geophysical detection, and many others.

5. The Scientific, Engineering, and Legal basis to Expand Early Action and Interim Remediation at contaminated sites.

South Africa has no clear guidelines when to employ early remedial measures at a site. The lack of unambiguous procedures results in confusion, with regulators sometimes disallowing quick action or responsible parties not taking the initiative. This can result in the delay of helpful interim measures. Early cleanup, sometimes called stabilization is presently considered “emergency action” in South Africa. However, early action can have a number of sizable benefits, even when it is not an “emergency” situation. These benefits can include plume containment, testing of remedial options and equipment, and source control. Procedures and response for actual emergency situations is also important, but does not appear to be uniform in the country. Standardized, consistent guidance is needed. The development of dependable procedures that encourage early action is needed, even for situations where no emergency exists, but there is tangible benefit from quick response.
6. **Addressing the Challenge of Small Waste Generators.**
   
   South Africa has made remarkable progress in addressing sites and polluters where large quantities of contamination have been released. This is an important and laudable pursuit. The experience in many other nations is that, additionally, small waste generators are so numerous that they create an additional, huge environmental challenge. Coupled with the situation that even small quantities of some pollutants can sizably increase health risk and environmental damage, these “minor” releases collectively create a sizable problem. The challenge of environmental agencies dealing with small operators is complicated where there are few land use records, a little industrial manifesting of chemical use, and/or a paucity of waste disposal records. South Africa has a great future challenge in identifying the magnitude and distribution of small waste generators, and devising a strategy for tackling this problem.

   Small polluters could include dry cleaning operations, petroleum stations, all manner of light industry, livestock areas and slaughter houses, and many other sources in a variety of locales. Some of the research tasks focusing on small generators of contamination should deal with organizing local surveys on small generators, investigating the establishment of a revolving fund for use for those who can not pay for a proper site assessment and cleanup, and deciding how best to assist local authorities in developing and implementing guidelines.

7. **Developing Concentration Based Action Levels**
   
   Many nations have concentration based action levels for many different contaminants in water. South Africa has developed some minimum acceptable concentration level for selected contaminants and water uses, but there are many chemicals which have no concentration-based level for triggering a regulatory response. Action levels (concentrations) for a broad spectrum of specific contaminants, if developed for South Africa, would give uniform guidance to industry, the public, decision makers, and to the regulatory community.

   A research approach to investigating the feasibility of establishing minimum numerical water quality standards has many advantages. Research could define appropriate minimum concentrations for each of a broad list of chemicals, levels that would initiate a regulatory response. The research could also develop recommendations for what form(s) the regulatory response should take. For example, the minimum concentration-based action standards could trigger risk assessment or other actions including interim remediation (stabilization).

8. **Regulatory Coordination Aspects.**
   
   South Africa’s regulatory community is moving in a direction of increasing local responsibility in dealing with water quality challenges. The balance and coordination between national and local duties is evolving. In addition, regulatory responsibilities on the national level are divided (and in some cases appear fragmented) between different agencies. In this context, research is needed to assist optimal coordination and future responsibilities between regulatory entities.
As the general direction shifts to more local primacy, the emphasis shifts from national guidance to more site specific requirements. In this transition, uniform interpretation and implementation of regulations must be maintained throughout South Africa, but the precise constraints and field realities of individual sites must be acknowledged. Information and management changes can be anticipated with scaling to small, unique localities. The key role research can provide is to smooth this transition and proactively suggest better efficiency to the changing regulatory landscape.

9. **Prioritization of Contaminant Sites – National Priorities List**

   A possible line of research would be to develop the criteria to make a national priorities inventory, that is, listing the contaminated sites in South Africa that pose the greatest risk to citizens and the environment in prioritized order. Of all the recommendations in this document, this is the one that may not fit into the present regulatory setting. The major benefit of such a Priorities List would be to focus resources on challenges of national importance. However, it is possible that, if not carried out properly, such a listing in South Africa might move cooperating industries into a more protective and cautious cleanup stance, and encourage inaction for those with a low listing.

10. **Developing a Common National Vision on How Monitored Natural Attenuation and Technical Impracticability Should be Considered and Implemented**

    The concepts of Monitored Natural Attenuation and Technical Impracticability are not uniformly defined in South Africa. The lack of a common understanding is not restricted to industry and the public, but regulators from the same agency often have a profoundly different concept regarding what these terms mean and how these are to be effectively implemented. Monitored Natural Attenuation is not a “walk-away” solution to water quality problems, nor is it a presumptive solution to water quality concerns. Likewise, a decision on technical impracticability of remediation often requires long term monitoring, consideration of new cleanup methodologies, and periodic review. Guidance and directives must promote a common national vision on how Monitored Natural Attenuation and Technical Impracticability should be considered. Research would assist regulators by addressing how new guidance could best direct future efforts. The program would develop clear, uniform directives which are widely distributed on how Monitored Natural Attenuation and Technical Impracticability are to be considered and implemented.

11. **Future Water Quality Analysis Needs in South Africa**

    Water quality analysis in South Africa is growing and developing, and there is a commensurate increase in workload on laboratories. With this growth comes many challenges. For example, there are too few laboratories that conduct full analyses, and there is a need in the analytical chemistry laboratory industry for standardization and more proficiency in organic analysis of water. Usher (2004) made additional recommendations (see #2 above) that rapid detection of microorganisms be prioritized as an area of future water quality study. South Africa is involved in testing and ranking its laboratories, however as a general rule, water quality measurements, sampling and analysis is not standardized. Laboratory quality varies and field collection of samples is
also not uniform. Consistent numbers or percentages of split samples, duplicate samples, field and lab blanks, spiked samples, and blind samples are not applied, sometimes not even at the same field site. Nor is there guidance as to what field screening methods are appropriate. This is an optimal time to plan and anticipate future needs for water quality measurement in the country, and to seek standard, reliable methods to sample and analyze water quality in the future.

12. **Surface - Groundwater Interactions and the Hyporheic Zone**

There is currently much work being done on crucial surface - groundwater interactions in South Africa. These interactions are extremely important to human health and ecosystem welfare, and can be sensitive to subtle changes in flow or quality. Likewise, protection of the hyporheic zone and its link between surface water and groundwater is of primary concern to good water resource management. Parsons and Associates reported summary information on these interactions in South Africa, and specific studies have been carried out. The South African Water Research Commission has rightfully recognized and supported studies in various field settings, and should commended in those efforts. Because of the critical nature of these interactions, future field studies on specific field sites should continue, and be expanded.

13. **Data Uniformity, Usability, and Completeness in Reporting for WRC Projects, and in South African Data Bases.**

A tremendous national challenge rests in consolidating the way water and water quality data is reported, and in some cases not reported in South Africa. Information reported to the South African government is often scattered, not in electronic form, is not standardized, is not consistently Geographical Information System (GIS) compatible, and in some cases is in a form that discourages full reporting. Likewise, the Water Research Commission has data reported to them in project documentation that is not always in standard, retrievable, user-friendly format.

In South Africa there is no one data management system for water-related information. For example, in Gauteng there is the WMS system which is good for surface water parameters, in Limpopo and some Eastern Cape areas there is the GRIP system, in the Western Cape there is the REGIS system, and the National Water Act created the widely used WARMS system which is not always user friendly and is property based. The National Groundwater Data Base is largely geared toward water supply and quantity, not quality, and generally the water quality data is better for rural areas, not urban. The water quality data which the national base contains are largely inorganic, not organic, parameters and the water quality data are largely from a snapshot at one time (often when the well went in), and not repeated, continuous monitoring (no time series).

Information comes from different requirements, is overseen by different agencies, and even can encourage under-reporting. Water information from mines can go into an Environmental Management Plan Report (EMPR), water quality management is often handled by a WMS system, there are separate sewage regulations and sanitation protocols, and much of this information is not electronic; hardcopies only. There is also a
perception that some practitioners are reluctant to make findings available. In one specific example of how the existing protocols could discourage full disclosure one could look to South Africa’s water use licensing, registration, and general authorization system. The required forms are not electronic, (Form 779,789, etc.), and have lots of pages. In one of those forms, each water use only has five lines for written data entry (e.g. If you have more than five boreholes for a given water use, you must either not report any more than five, or list the additional wells as a separate water use).

Research is needed to build a more robust, unified, better water data base. This data base should be electronic and GIS compatible. Agencies should enforce the collection and compilation of all groundwater quality data, in electronic form, and include it in the data base in a timely manner. Existing data information systems should be unified, not miss important parameters and be readily available. There should also be uniformity in reporting data in WRC Projects; optimally these data would be compatible with DWAF and other national formats, and incorporate time series information.

14. Examining Groundwater Models: Their Applicability, and the Data Necessary to Populate a Model
   The usage of mathematical models, particularly numerical models, to simulate water resource phenomena is increasing in South Africa. Research is needed to better understand model applicability, to delineate the amount of data necessary to populate a model, and to understand scaling issues in the South African context. This work should go a long way in providing understanding about the strengths and weaknesses of models. The reliability and appropriateness of modeling approaches is of pivotal importance in future water resource management and prediction.

15. Expanding Training and Information Dissemination
   The Water Resources Commission has wisely included training and information dissemination as an integral part of their funded research projects. This practice has many benefits, such as capacity building and distributing research results to potential users. The WRC should continue to emphasize training and capacity building, and where it can, sponsor research seminars and conferences. Because many government resource agencies could benefit from training, coupling training efforts with these agencies would be effective and commensurate with the WRC’s mission. Research could also investigate how to increase effective public forums and public input on water issues. Lastly, the training aspects of the WRC program are so valuable that expanding this to neighboring countries would be a natural extension of the current program.

16. Establishing and Strengthening International Partnerships
   South African scientists and engineers have much to gain by strengthening international partnerships, and much to share and give to the international community as well. Links and exchange with international scholars and professional organizations could provide advantages for local researchers. This cooperation can be on small and large scale efforts. On a project scale this includes such activities as comparing local data to overseas data, or by jointly authoring publications and research proposals with researchers from other countries. As mentioned above, expansion of South African
training to neighboring countries is a natural extension of the WRC’s work. Finally, the Commission could play a major role in backing philanthropic water resource management efforts – there is great potential and need for creating and sustaining international programs of education, emergency remediation, water supply, and rehabilitation in Sub Saharan Africa.