**Table 9-1 Impact Assessment, pre- and post-mitigation, for the Alexander Project.**

| CONSTRUCTION | Intensity | Duration | Extent | Consequence | Significance | Intensity | Duration | Extent | Consequence | Significance | Main Mitigation Measures |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **SHAFT COMPLEX** | | | | | | | | | | | |
| Sediment Transport into Wetlands | Medium | Short-term | Medium | Medium | High | Low | Short-term | Medium | Medium | High | Sediment trapping, attenuate stormwater flows, wetlands demarcated as no-go areas. Educate staff regarding the importance of wetlands |
| Erosion due to stormwater | Medium | Short-term | Medium | Medium | High | Low | Short-term | Medium | Medium | Medium | Stormwater management, attenuate flows, no releases directly into wetlands |
| Decline in Water quality | Medium | Short-term | Medium | Medium | High | Low | Short-term | Medium | Medium | Medium | Manage spills/leaks, hazardous waste, stormwater |
| Spread of Alien Fish | High | Long term | High | Very High | Medium | Very Low | Long term | High | Medium | Low | No stocking of alien fish |
| Spread of alien vegetation | Low | Long term | Medium | Medium | Medium | Very Low | Long term | Medium | Medium | Medium | Alien vegetation Management Plan |

| CONSTRUCTION | Intensity | Duration | Extent | Consequence | Significance | Intensity | Duration | Extent | Consequence | Significance | Main Mitigation Measures |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Loss of species/Decline in ecological integrity | Low | Medium term | Medium | Medium | Medium | Very Low | Medium term | Medium | Medium | Medium | Manage water quality, habitats and flow. Implement a Biodiversity Management Plan |
| **CONVEYOR** | | | | | | | | | | | |
| Decline in pan habitat and biota | Medium | Long-term | Very Low | Medium | High | Low | Long-term | Very Low | Medium | Medium | Consider pan basins (including surrounding buffer) no-go areas. Prevent runoff and sediment transport into pan basin. Runoff to be directed into grassed verges outside of wetland areas. Dust suppression on untarred roads. Protect any habitats identified as Giant bullfog habitat. Implement Biodiversity Management Plan |
| Sediment transport into wetlands | Medium | Short-term | Medium | Medium | High | Medium | Short-term | Medium | Medium | Medium | Sediment trapping. Ensure attenuated flows of stormwater into grassed verges and not directly into wetland areas. Wetlands and pans demarcated as no-go areas. Avoid wetland crossings, if possible. |
| Erosion of wetlands due to accelerated flows and stormwater runoff | Low | Short Term | Medium | Medium | Medium | Low | Short Term | Medium | Medium | Medium | Avoid wetland crossings, if possible. Where unavoidable, crossings to span the wetland to minimise disturbance. Culverts must be large enough to avoid disrupting flow patterns. Runoff to be attenuated and directed into grassed verges and not directly into wetlands. Wetlands demarcated as no-go areas. |
| Deterioration in water quality and loss of sensitive species | Medium | Short term | Medium | Medium | High | Medium | Short term | Medium | Medium | Medium | Cordon off wetlands and pans and prevent access. Manage spills/leaks, hazardous waste. Attenuate stormwater runoff into grassed verges and not directly into wetlands. Trap sediments. Dust suppression. |
| Loss of Fish and Amphibians | Medium | Very long term | Medium | High | High | Medium | Short term | Medium | Medium | Medium | Manage water quality, habitats and flow. Conveyor footprint and construction activities to remain outside of wetlands and pan basins (including catchment). Runoff to be managed to avoid decline in water quality and habitat deterioration (erosion and sedimentation) within receiving wetlands. Compile and implement a Biodiversity Management Plan. |

| OPERATIONAL | Intensity | Duration | Extent | Consequence | Significance | Intensity | Duration | Extent | Consequence | Significance | Main Mitigation Measures |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **MINING** | | | | | | | | | | | |
| Altered flows due to subsidence | Low | Permanent | Medium to High | Medium to High | Medium to high | Very Low | Permanent | Medium | Medium | Medium | No undermining of channelled valley bottom wetlands and floodplaain wetlands (in particular, the Steenkoolspruit and Piekespruit). No total extraction beneath wetlands. |
| Contamination of groundwater | High to Very High | Very long term | High to Very High | High to Very high | Very High | High | Long term | High | Medium | High | Use appropriate lining for the waste rock dump; Prevent ingress of water into underground workings. Treat mine water to acceptable level and return to the environment. |
| Decline in water quality (AMD and decant) | Very High | Very Long | Very High | Very High | Very High | Medium to High | Very Long | Medium to High | High | High | Treat mine water to acceptable level and return to the environment. Prevent ingress of surface water into underground workings |
| Loss of aquatic biota | High | Permanent | High (to Very High) | Very High | High | Medium | Permanent | Medium | High | High | Manage water quality, habitats and flow; Biodiversity Management Plan |
| Decline in habitats (blasting) | Low | Long term | Low | Medium | Medium | Very Low | Long term | Low | Medium | Medium | Stabilise banks and rehabilitate wetlands |

| OPERATIONAL | Intensity | Duration | Extent | Consequence | Significance | Intensity | Duration | Extent | Consequence | Significance | Main Mitigation Measures |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **SHAFT COMPLEX** | | | | | | | | | | | |
| AMD (waste rock dump) | High | Long-term | High | High | High | Medium | Long-term | High | High | High | Use appropriate lining for the waste rock dump; prevent pooling of water; separate clean and dirty stormwater. |
| Water quality deterioration (coal contaminants) | Low | Long term | Medium | Medium | High | Very Low | Long term | Medium | Medium | Medium | Prevent spills of coal or coal dust, ensure coal dust is washed into dirty water system |
| Water quality deterioration (spills/leaks) | Low to High | Short term | Medium to Very | Medium to High | Medium to High | Low | Short term | Medium | Medium | Medium | Manage spills/leaks, hazardous waste, stormwater separation |
| Water quality deterioration (major spills) | Very High | Short term | High to Very High | Medium to High | Medium to High | Very High | Short term | High to Very High | Medium to High | Medium | Compile emergency preparedness plan |
| Habitat decline due to stormwater/erosion | Low | Long term | Medium | Medium | Medium | Very Low | Long term | Medium | Medium | Medium | Stormwater management, attenuate flows, no releases directly into wetlands |
| Habitat decline due to sedimentation | Low | Long term | Medium | Medium | Medium | Very Low | Long term | Medium | Medium | Medium | Sediment trapping, attenuate stormwater flows, wetlands demarcated as no-go areas. Educate staff regarding the importance of wetlands |

| OPERATIONAL | Intensity | Duration | Extent | Consequence | Significance | Intensity | Duration | Extent | Consequence | Significance | Main Mitigation Measures |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Habitat decline due to alien vegetation | Low | Long term | Medium | Medium | High | Low | Long term | Medium | Medium | Medium | Alien Vegetation Management Plan |
| Impacts to fish abundance and distribution | High | Long term | High | High | Medium | High | Long term | High | High | Medium | Manage water quality, habitats and flow. Implement a Biodiversity Management Plan. No instream dams or weirs. No introduction of alien fish species. |
| **Conveyor** | | | | | | | | | | | |
| Decline in pan habitat and biota | Medium | Medium | Low | Medium | High | Medium | Medium | Low | Medium | Medium | Consider pan basins (including surrounding catchments) as no-go areas. Prevent spills of coal or coal dust. Prevent runoff and sediment transport into pan basin. Dust suppression on untarred roads. Implement Biodiversity Management Plan. Protect Giant bullfrog habitat (where applicable) |
| Decline in water quality | Medium | Long term | Medium | Medium | High | Low | Long term | Medium | Medium | Medium | Sediment trapping. Prevent spills of coal or coal dust. Stormwater to be attenuated and directed away from wetland areas. Dust suppression on untarred roads. Emergency preparedness plan in the event of major spills. |
| Decline in habitat integrity (sedimentation/erosion) of tributaries | Medium | Long term | Medium | Medium | High | Low | Long term | Medium | Medium | Medium | Culverts must be large enough to avoid disrupting flow patterns and should be kept clear to avoid flow obsstructions. Runoff to be attenuated and directed into grassed verges and not directly into wetlands. |
| Decline in biodiversity | Medium | Long term | Medium | Medium | High | Low | Long term | Medium | Medium | Medium | Wetlands and pans to be considered no go areas (including buffers). Runoff to be managed to avoid decline in water quality and habitat deterioration (erosion and sedimentation) within receiving wetlands. Implement biodiversity management plan. |

| DECOMMISSIONING AND CLOSURE | Intensity | Duration | Extent | Consequence | Significance | Intensity | Duration | Extent | Consequence | Significance | Main Mitigation Measures |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **MINING** | | | | | | | | | | | |
| Altered flows due to subsidence | Low | Permanent | Medium to High | Medium to High | Medium to high | Very Low | Permanent | Medium | Medium | Medium | No undermining of channelled valley bottom wetlands and floodplaain wetlands (in particular, the Steenkoolspruit and Piekespruit). No total extraction beneath wetlands. |
| Groundwater contamination and AMD | High to Very High | Very long term | High to Very High | High to Very high | Medium to High | High | Long term | High | Medium | High | Use appropriate lining for the waste rock dump; Prevent ingress of water into underground workings. Treat mine water to acceptable level and return to the environment. |
| Decline in water quality (decant) | Very High | Very Long Term | Very High | Very High | Very High | Medium to High | Very Long Term | Medium to High | High | High | Treat mine water to acceptable level and return to the environment. Prevent ingress of surface water into underground workings |
| Loss of aquatic biota | High | Permanent | High (to Very | Very High | High | Medium | Permanent | Medium | High | High | Manage water quality, habitats and flow; Biodiversity Management Plan |

| DECOMMISSIONING AND CLOSURE | Intensity | Duration | Extent | Consequence | Significance | Intensity | Duration | Extent | Consequence | Significance | Main Mitigation Measures |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **SHAFT COMPLEX** | | | | | | | | | | | |
| Water quality deterioration (due to coal contaminants) | Low | Long-term | Medium | Medium | Medium | Very Low | Short term | Medium | Medium | Medium | Prevent spills of coal or coal dust, ensure coal dust is washed into dirty water system |
| Water quality deterioration (due to spills/leaks) | Low | Short-term | Medium | Medium | High | Very Low | Short-term | Medium | Medium | Low | Manage spills/leaks, stormwater |
| Water quality deterioration (due to hazardous waste) | Low | Short-term | Medium | Medium | Medium | Very Low | Short-term | Medium | Medium | Low | Dispose of all solid and hazardous waste at registered facility |
| Habitat decline due to stormwater/erosion | Low | Short term | Medium | Medium | Medium | Very Low | Short-term | Medium | Medium | Low | Stormwater management, attenuate flows, no releases directly into wetlands |
| Habitat decline due to sedimentation | Low | Short term | Medium | Medium | Medium | Very Low | Short-term | Medium | Medium | Medium | Sediment trapping, attenuate stormwater flows, wetlands demarcated as no-go areas. Educate staff regarding the importance of wetlands |

| DECOMMISSIONING AND CLOSURE | Intensity | Duration | Extent | Consequence | Significance | Intensity | Duration | Extent | Consequence | Significance | Main Mitigation Measures |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Habitat decline due to alien vegetation | Medium | Long term | Medium | Medium | High | Low | Short term | Medium | Medium | Medium | Alien Vegetation Management Plan |
| **Conveyor** | | | | | | | | | | | |
| Water quality deterioration (due to spills and leaks) | Low | Short-term | Medium | Medium | Medium | Very Low | Short-term | Medium | Medium | Low | Manage spills/leaks, stormwater |
| Decline in water quality (due to hazardous waste) | Low | Short-term | Medium | Medium | Medium | Very Low | Short-term | Medium | Medium | Low | Dispose of all solid and hazardous waste at registered facility |
| Decline in habitat integrity (due to sedimentation/erosion) | Low | Short term | Medium | Medium | Medium | Very Low | Short-term | Medium | Medium | Medium | wetlands and pans to be considered no-go areas. Stormwater management, attenuate flows, no releases directly into wetlands |
| Habitat decline due to alien vegetation | Low | Long term | Medium | Medium | High | Low | Short term | Medium | Medium | Medium | Alien Vegetation Management Plan |

## 9.5 Recommendations for Biomonitoring

It is recommended that the sampling sites used in this survey be used during biomonitoring, with the possible addition of sampling sites upstream and downstream of proposed developments.

Biomonitoring protocols should include:

- SASS5, together with a habitat assessment (e.g. IHAS)
- Fish
- Diatoms at sites upstream and downstream of the shaft complex
- Wetland monitoring (This should include monitoring of the main drivers of wetland function – water quality, erosion/sedimentation, vegetation and hydrology)

In addition, WET toxicity testing should be conducted on water sampled from pollution control facilities (to determine the risk of causing toxicity in the event of controlled or uncontrolled releases).

Biomonitoring should be conducted biannually (wet and dry season), while toxicity testing should be conducted quarterly. A baseline survey should be conducted prior to the commencement of construction.

# 10 SUMMARY AND CONCLUSIONS

***Summary of Baseline Environment***

The Piekespruit had the highest biotic integrity in terms of habitats, aquatic macroinvertebrates and fish. The upstream site was considered Largely Natural (PES B), with a high diversity of fish and aquatic macroinvertebrates and a relatively high prevalence of sensitive taxa. However, the biotic integrity decreased in a downstream direction to a PES C (Moderately Modified condition) upstream of its confluence with the Steenkoolspruit. This was as a result of erosion, particularly below farm dams, which has reduced the availability and suitability of marginal habitats. The decline in biotic integrity was mainly a response to declining habitats and not to water quality impacts. This means that rehabilitation of habitats is likely to be followed by improved integrity.

Otter tracks were recorded along the Piekespruit and the upper reach of the Steenkoolspruit, indicating adequate availability of favourable habitat and their preferred food source (crabs, mussels, fish).

The Steenkoolspruit, upstream of the confluence with the Piekespruit, was considered, for the most part, to be Largely Natural to Moderately Modified (PES B-C) at a reach level, with some variation between individual sites. Biotic responses within this reach were mainly to habitat deterioration as a result of severe erosion and channel incision. Responses to water quality impacts were not pronounced, again indicating that restoration of habitats is likely to be followed by improved biotic conditions.

Downstream of the confluence between the Piekespruit and Steenkoolspruit, habitat integrity declined markedly as the channel becomes deeply incised and marginal habitats decline. The Steenkoolspruit was classified as Largey Modified (PES D) downstream of the confluence with the Piekespruit. The most downstream reach, adjacent and downstream of Kriel Town, was classified as Largely to Seriously Modified (PES D/E). Considerable water quality impacts were observed within this reach and sensitive taxa were completely absent.

Tributaries of the Olifants River and Viskuile River that will be impacted upon by the conveyor (sites SK-Trib, V-Trib and O-Trib) were considered to have good water quality (with a high diversity of aquatic macroinvertebrates), and to provide favourable pool habitats for dragonflies and damselflies, juveniles of indigenous fish species and amphibians, as well as otter. They are thought to play a role in supporting populations of indigenous fish species within the receiving Olifants River, where water quality impacts and predation by exotic species (mostly carp) are problematic. The wetland system that drains into the Viskuile River (Vlakkuilenspruit) to the east is thought to be particularly important in this regards. For this reason, these tributaries are considered sensitive and important in terms of supporting biodiversity within the study area.

Finally, a number of seasonal pans within the study area add to the overall biodiversity by providing suitable conditions for specialised pan-adapted fauna (such as copepods, ostracods and cladocerans). The abundance of crustaceans and planktonic organisms in these pans supports a diversity of water birds, including flamingos (greater and possibly lesser). These pans therefore provide an important habitat and food supply for migratory bird species. It should be noted that, although not all pans within the study area were sampled, they should be regarded as having high biodiversity importance. Pans 5 and 6 were considered to be the most seasonal in nature. The potential presence of Giant bullfrog in these pans (and others within the study area) should be investigate prior to construction.

***Impact Assessment and Management Recommendations***

The most significant impacts associated with the proposed development include:

- The Steenkoolspruit is already severely eroded and channelized and it is expected that runoff from the shaft area will exacerbate this problem.
- Should subsidence occur in wetland areas, there may be a loss of surface water to groundwater, resulting in decreased flows in the receiving watercourses. This, in turn, will exacerbate water quality issues and habitat integrity (e.g. exposure of banks to erosion).
- It is likely that some degree of AMD will occur although the severity and extent are uncertain (see geohydrology study for further detail). Contaminated groundwater is likely to emerge in wetlands, causing a decline in water quality. Exactly where the contamination will occur cannot be exactly predicted.
- Surface water is likely to become more acidic, saline and metal-rich as a result of contaminated runoff (containing, for example, coal dust) and possible groundwater contamination.
- The greatest risk associated with any mining project is that of decant once the underground workings have filled with water post-closure. The potential decant points are not known. Depending on where the decant takes place, there is a risk that surface water will become contaminated over a large extent, extending well into the Olifants River system.
- There are likely to be impacts to biodiversity within the seasonal pans adjacent to the conveyor, mostly as a result of dust, spills and possible stormwater inputs. These can be easily mitigated by ensuring that pans, together with their catchment areas, be considered no-go areas and that vehicular access is prevented.
- The conveyor route will also affect water quality and habitats within wetland tributaries of the Olifants River and Viskuile River. Sensitive species will be lost and habitats (e.g. for amphibians, dragonflies and damselflies, fish and otter) will be compromised. Overall biodiversity will therefore decline. Fish are particularly sensitive to changes in pH to below 6.5.

Recommendations for mitigation of the above impacts include:

Contamination of groundwater, as well as subsidence and decant, are impacts that are difficult to predict and effectively mitigate. It is therefore recommended that the focus should be placed on preventing ingress of surface water into underground workings. Ideally, wetlands should not be undermined at all. In particular, channelled valley bottom and floodplain wetlands should not be undermined. Total extraction should be avoided beneath all wetlands (together with their recommended buffer zones). It is recommended that the risks of subsidence and ingress be determined and that ground water-surface water links be identified, where possible. Potential decant points should be identified and the long term treatment of mine water must be considered.

AMD associated with the waste rock dump must be mitigated by using an appropriate lining and ensuring that dirty water is effectively channeled into the dirty water stormwater system.

Disturbance of seasonal pans and their biota, must be kept to a minimum. Pans, including their catchment areas, should be considered no-go areas and vehicular access must be prevented. The potential presence of giant bullfrog within pans in the study area should be investigated (especially in Pans 5 and 6). A biodiversity management plan should be compiled and implemented for all aquatic ecosystems.

Additional mitigation measures that have been proposed include:

- Wetlands should be considered no-go areas to construction vehicles. Habitat corridors for fish, amphibians and otter should be maintained by avoiding construction in wetland areas and by ensuring the availability of good quality water and habitat.
- Minimize sediment transport into wetlands (e.g. by using sediment traps)
- Avoid leaks and spills (including of coal and of contaminated mine water) that can contaminate surface waterbodies
- Manage stormwater so as to prevent erosion in receiving wetlands
- Manage waste, including hazardous waste responsibly
- Manage biodiversity by preventing introduction of alien bass or carp, compiling and implementing a biodiversity management plan, compiling and implementing an alien vegetation management plan, conducting regular monitoring and biomonitoring, with follow up actions taken on recommendations made (biomonitoring cannot be regarded as mitigation if no follow up action is taken) and ensuring habitat and water quality impacts are managed.
- Minimise abstraction from boreholes (to prevent a lowering of the water table and reduced flows in receiving watercourses)

It is additionally recommended that a wetland rehabilitation plan be compiled for wetlands within the Alexander study area. This should focus on managing erosion and sedimentation within channelled systems.

***Conclusion***

Most impacts can be mitigated to an acceptable level. However, contamination of groundwater, as well as subsidence and ingress, are impacts that are difficult to predict and effectively mitigate. The significance of this impacts are therefore rated as High due to lack of certainty. Impacts due to decanting mine water are likely to be highly significant.

Despite implementation of all the recommended mitigation, some degree of water quality deterioration (through spills, leaks, seepage, etc.) and habitat loss or deterioration (mainly through erosion and sedimentation) will be inevitable. Surface water is likely to become increasingly acidic, saline and metal-rich. This will cause a decline in aquatic biota, particularly those with a high requirement for good water quality. There may be a decline both in terms of abundance and diversity, with possible impacts on animals higher up in the food chain (such as otter and birds). It is likely that the PES of the Steenkoolspruit (upstream of the confluence with the Piekespruit) will decline in integrity from a Category C (Moderately Modified) to a Category D (Largely Modified). The Olifants and Viskuile Tributaries are likely to decline from a PES B to a PES C/D (based on SASS5), with impacts transferred to the receiving Olifants River.

Should contamination of groundwater or decant occur, the deterioration in the quality of water in receiving watercourses will be far higher and extend far further into the Olifants River system.

# 11 REFERENCES


CEMAGREF.1982. Etude des méthodes biologiques quantitatives d'appréciation de la qualité des eaux. Rapport Division Qualité des Eaux Lyon - Agence Financiére de Bassin Rhône- Méditerranée- Corse. Pierre-Benite

Clean Stream Biological Services 2013. Biomonitoring and toxicity testing of the receiving water bodies in the vicinity of Lonmin Platinum (Marikana operations) – May 2013 survey.

Dallas, H.F., Day, D. E., 1993. The effect of water quality variables on riverine ecosystems: a review. WRC Report No. TT 61/93. Water Research Commission, Pretoria.

Davies, B. and Day, J. (1998). Vanishing Waters. University of Cape Town Press, Cape Town, South Africa. 487pp.

De Moor IJ and Bruton MN (1988). Atlas of alien and translocated indigenous aquatic animals in southern Africa. South African National Scientific Programmes Report No 144/1988. South Africa. 310pp.

Department of Water Affairs and Forestry. 1999. *Resource Directed Measures for Protection of Water Resources.* Volume 1. River Ecosystems Version 1.0, Pretoria.

Dickens, C.W.S. and Graham, P.M. (1998). Biomonitoring for effective management of wastewater discharges and health of the river environment. J. Aquat. Ecosyst. Health. 1 199-217.

Dickens, C.W.S., Graham, P.M., 2002. The South African Scoring System version 5 rapid bioassessment system for rivers. African Journal of Aquatic Science 27, 1-10.

IUCN. 2012. International Union for Conservation of Nature and Natural Resources. Red list of threatened species. www.iucnredlist.org.

Kemspter, P.L, Hattingh, W.A.J. & Van Vliet, H.R. 1980. Summarized water quality criteria. Department of Water Affairs, forestry and environmental Conservation, Pretoria. Technical Report No TR 108. 45pp.

Kleynhans, C.J. 1996. A qualitative procedure for the assessment of the habitat integrity status of the Luvuvhu River. *Journal of Aquatic Ecosystem Healt*h 5: 41 - 54.

Kleynhans, CJ (1997). An exploratory investigation of the Instream Biological Integrity of the Crocodile River, Mpumalanga, as based on the Assessment of Fish Communities. Draft Report, Department of Water Affairs and Forestry, Institute for Water Quality Studies. 61 pp.

Kleynhans, CJ (1999). The development of a fish Index to assess the biological integrity of South African rivers. Water SA 25(3): 265-278.

Kleynhans CJ (2003). National Aquatic Ecosystem Biomonitoring Programme: Report on a National Workshop on the use of Fish in Aquatic System Health Assessment. NAEBP Report Series No. 16. Institute for Water Quality Studies, DWAF, Pretoria. South Africa.

Kleynhans, CJ, Thirion, C and Moolman, J (2005). A Level I River Ecoregion classification System for South Africa, Lesotho and Swaziland. Report No. N/0000/00/REQ0104. Resource Quality Services, Department of Water Affairs and Forestry, Pretoria, South Africa.

Kleynhans CJ (2008). Module D: Fish Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2) Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT330/08.

Kleynhans CJ, Louw MD, Moolman J. (2007). Reference frequency of occurrence of fish species in South Africa. Report produced for the Department of Water Affairs and Forestry (Resource Quality Services) and the Water Research Commission.

Kleynhans CJ & Louw, MD (2008). Module A: Ecoclassification and Ecostatus determination: River Ecoclassification Manual for EcoStatus Determination (version 2) Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT329/08.

Koekemoer. S. and J. Taylor. 2011. Rapid methodology for inferring wetland water quality based on diatom analysis. Manual for the Rapid Ecological Reserve Determination of Wetlands (Version 2.0). Department of Water Affairs.

Krammer, K. and H. Lange-Bertalot. 2000. Süßwasserflora von Mitteleuropa, Bd. 2/2: Bacillariophyceae: Teil 2: Bacillariaceae, Epithemiaceae, Surirellaceae. Spektrum Akademischer Verlag GmbH. Berlin Ed.

Lecointe, C, Coste, M and Prygiel, J (1993). “Omnidia”: Software for taxonomy, calculation of diatom indices and inventories management. Hydrobiologia 269/270: 509-513.

Odum, E.P. (1971). Fundamentals of Ecology. Third Edition. W. B. Saunders Co. London. 310pp

Roux, D.J. (1999). Incorporating technologies for the monitoring and assessment of biological indicators into a holistic resource-based water quality management approach - conceptual models and some case studies. Ph.D Thesis. Rand Afrikaans University, Johannesburg, South Africa.

Skelton, P.H. 2001. A Complete Guide to the Freshwater Fishes of Southern Africa. Struik Publishers, Cape Town. 395pp.

Taylor, JC, Harding, WR and Archibald, CGM 2007. A methods manual for the collection, preparation and analysis of diatom samples. Water Research Commission Report TT281/07. Water Research Commission. Pretori

Uys, M.C., Goetch, P. A., & O'Keeffe, J. H., 1996. National Biomonitoring Program for Riverine Ecosystems: Ecological Indicators, a review and recommendations. NBP Report Series No. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria. South Africa.

Wolhuter L.E. & Impson D. (2007). The state of the Yellowfishes in South Africa, 2007. WRC Report no. TT 302/07, Pretoria, South Africa.

# 12 APPENDIX 1: SASS5 RESULTS

**Table 12-1. SASS5 results for Alexander aquatic sampling sites. (Sensitive taxa are highlighted in blue).**

| | | Piekespruit | | | Steenkoolspruit | | | | | | Olifants | | Viskuile | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Taxon | SASS Score | PS1 | PS2 | PS3 | SK-US | SK2 | SK3 | SK4 | SK5 | SK-DS | Olifants | Otrib | Viskuile | Vtrib |
| Oligochaeta | 1 | 1 | 1 | A | - | - | A | A | - | - | - | - | - | A |
| Potamonautidae* | 3 | - | 1 | 1 | - | 1 | - | A | - | A | - | - | - | 1 |
| Atyidae | 8 | A | A | A | A | - | 1 | A | B | - | A | - | B | A |
| HYDRACARINA | 8 | B | 1 | A | - | - | - | - | - | - | - | 1 | - | A |
| Baetidae 1 sp. | 4 | A | - | - | - | A | A | - | B | 1 | A | - | - | A |
| Baetidae 2 spp. | 6 | - | - | B | B | B | - | B | - | - | B | A | B | B |
| Baetidae >2 spp. | 12 | - | - | B | - | - | - | - | - | - | A | - | - | - |
| Caenidae | 6 | 1 | - | A | A | A | - | A | A | - | - | - | - | - |
| Oligoneuridae | 15 | - | - | - | - | A | - | - | - | - | - | - | - | - |
| Coenagrionidae | 4 | B | A | B | A | B | A | A | A | A | A | A | A | A |
| Lestidae | 8 | A | 1 | A | 1 | A | - | - | - | - | - | - | - | - |
| Aeshnidae | 8 | - | - | 1 | - | - | - | - | - | - | - | A | - | A |
| Belostomatidae* | 3 | A | - | A | A | 1 | 1 | A | A | A | 1 | A | A | A |
| Corixidae* | 3 | B | B | B | A | B | A | B | B | B | C | A | B | B |
| Gerridae* | 5 | A | A | A | - | - | A | A | - | - | B | A | B | A |
| Naucoridae* | 7 | - | - | - | - | A | 1 | 1 | - | - | - | - | - | - |
| Nepidae* | 3 | 1 | - | - | - | - | 1 | - | 1 | - | A | - | 1 | - |
| Notonectidae* | 3 | A | B | B | A | - | B | B | - | B | A | B | 1 | 1 |
| Pleidae* | 4 | A | - | A | - | - | - | - | A | A | - | A | A | 1 |
| Veliidae* | 5 | - | - | - | A | - | 1 | A | B | 1 | 1 | 1 | - | 1 |
| Hydropsychidae 1sp. | 4 | - | - | A | - | - | - | - | 1 | - | - | - | - | - |
| Hydropsychidae 2spp. | 6 | - | - | - | - | - | - | A | - | - | - | - | - | - |
| Hydroptilidae | 6 | - | A | - | - | - | - | - | - | - | - | - | - | - |
| Dytiscidae (adults*) | 5 | A | A | - | - | - | - | A | A | 1 | A | 1 | A | A |
| Gyrinidae (adults*) | 5 | A | A | B | A | A | - | A | A | - | 1 | - | - | - |
| Hydrophilidae (adults*) | 5 | - | A | - | - | - | 1 | A | - | 1 | 1 | 1 | A | A |
| Ceratopogonidae | 5 | A | - | - | 1 | A | 1 | A | 1 | 1 | A | - | 1 | 1 |
| Chironomidae | 2 | B | A | A | A | B | - | A | A | B | B | A | B | B |
| Dixidae* | 10 | - | - | - | - | - | - | - | - | - | - | - | 1 | - |
| Simuliidae | 5 | A | A | B | A | B | - | B | A | - | A | - | - | - |
| Ancylidae | 6 | A | - | - | - | - | 1 | - | - | - | - | - | A | A |
| Lymnaeidae* | 3 | - | A | - | - | - | - | - | - | - | - | - | - | - |
| Physidae* | 3 | A | A | A | - | - | - | - | - | - | A | A | A | A |
| Planorbinae* | 3 | - | 1 | - | - | - | - | - | - | - | - | - | - | - |
| Sphaeridae | 3 | - | A | 1 | A | - | - | - | - | - | - | - | - | - |
| Unionidae | 6 | - | - | - | - | - | - | 1 | - | - | - | - | - | - |
| Total SASS5 score | | 95 | 91 | 98 | 66 | 76 | 62 | 97 | 66 | 46 | 76 | 64 | 75 | 93 |
| No. of families | | 21 | 20 | 20 | 14 | 14 | 14 | 21 | 15 | 12 | 16 | 14 | 16 | 20 |
| ASPT | | 4.52 | 4.55 | 4.90 | 4.71 | 5.43 | 4.43 | 4.62 | 4.40 | 3.83 | 4.75 | 4.57 | 4.69 | 4.65 |
| Habitat Suitability Score (max 45) | | 15 | 14 | 17 | 10 | 19 | 14 | 18 | 12 | 9 | 11 | 9 | 10 | 10 |
| PES (Dallas 2007) | | B | B | B | C | B | C | B | C | E | C | C | B | B |

# 13 APPENDIX 2. FRAI RESULTS

**Table 13-1: Fish Response Assessment Index (FRAI) results for sub-quaternary reach B11C-1501 (upper Piekespruit reach).**

| METRIC GROUP | METRIC | *RATING (CHANGE) | METRIC GROUP WEIGHT (%) |
|---|---|---|---|
| VELOCITY-DEPTH CLASSES METRICS | Response of species with high to very high preference for FAST-DEEP conditions | 0.0 | 95.6 |
| | Response of species with high to very high preference for FAST-SHALLOW conditions | 0.0 | |
| | Response of species with high to very high preference for SLOW-DEEP conditions | -1.0 | |
| | Response of species with high to very high preference for SLOW-SHALLOW conditions | -1.0 | |
| COVER METRICS | Response of species with a very high to high preference for overhanging vegetation | -1.0 | 100 |
| | Response of species with a very high to high preference for undercut banks and root wads | 0.0 | |
| | Response of species with a high to very high preference for a particular substrate type | 0.0 | |
| | Response of species with a high to very high preference for instream vegetation | -1.0 | |
| | Response of species with a very high to high preference for the water column | -2.0 | |
| FLOW DEPENDANCE METRICS | Response of species intolerant of no-flow conditions | 0.0 | 77.9 |
| | Response of species moderately intolerant of no-flow conditions | 0.0 | |
| | Response of species moderately tolerant of no-flow conditions | -1.0 | |
| | Response of species tolerant of no-flow conditions | 0.0 | |
| PHYSICO-CHEMICAL METRICS | Response of species intolerant of modified physico-chemical conditions | 0.0 | 63.2 |
| | Response of species moderately intolerant of modified physico-chemical conditions | 0.0 | |
| | Response of species moderately tolerant of modified physico-chemical conditions | -1.0 | |
| | Response of species tolerant of modified physico-chemical conditions | -1.0 | |
| MIGRATION METRICS | Response in terms of distribution/abundance of spp with catchment scale movements | | 51.5 |
| | Response in terms of distribution/abundance of spp with requirement for movement between reaches or fish habitat segments | 1.0 | |
| | Response in terms of distribution/abundance of spp with requirement for movement within reach or fish habitat segment | 1.0 | |
| INTRODUCED SPECIES METRICS | The impact/potential impact of introduced competing/predaceous spp? | 0.5 | 64.7 |
| | How widespread (frequency of occurrence) are introduced competing/predaceous spp? | 0.5 | |
| | The impact/potential impact of introduced habitat modifying spp? | 3.0 | |
| | How widespread (frequency of occurrence) are habitat modifying spp? | 3.0 | |
| **FRAI SCORE (%)** | | **84** | |
| **FRAI CATEGORY** | | **B** | |
| **FRAI CATEGORY DESCRIPTION** | | **Largely Natural** | |

**Table 13-2: Fish Response Assessment Index (FRAI) results for sub-quaternary reach B11C-1472 (lower Piekespruit reach).**

| METRIC GROUP | METRIC | *RATING (CHANGE) | METRIC GROUP WEIGHT (%) |
|---|---|---|---|
| VELOCITY-DEPTH CLASSES METRICS | Response of species with high to very high preference for FAST-DEEP conditions | 0 | 95.6 |
| | Response of species with high to very high preference for FAST-SHALLOW conditions | 0 | |
| | Response of species with high to very high preference for SLOW-DEEP conditions | -2.0 | |
| | Response of species with high to very high preference for SLOW-SHALLOW conditions | -1.0 | |
| COVER METRICS | Response of species with a very high to high preference for overhanging vegetation | -1.0 | 100 |
| | Response of species with a very high to high preference for undercut banks and root wads | -2.0 | |
| | Response of species with a high to very high preference for a particular substrate type | -4.0 | |
| | Response of species with a high to very high preference for instream vegetation | -1.0 | |
| | Response of species with a very high to high preference for the water column | -3.0 | |
| FLOW DEPENDANCE METRICS | Response of species intolerant of no-flow conditions | 0.0 | 77.9 |
| | Response of species moderately intolerant of no-flow conditions | -4.0 | |
| | Response of species moderately tolerant of no-flow conditions | -2.0 | |
| | Response of species tolerant of no-flow conditions | 0.0 | |
| PHYSICO-CHEMICAL METRICS | Response of species intolerant of modified physico-chemical conditions | 0.0 | 63.2 |
| | Response of species moderately intolerant of modified physico-chemical conditions | -4.0 | |
| | Response of species moderately tolerant of modified physico-chemical conditions | -1.0 | |
| | Response of species tolerant of modified physico-chemical conditions | -1.0 | |
| MIGRATION METRICS | Response in terms of distribution/abundance of spp with catchment scale movements | | 51.5 |
| | Response in terms of distribution/abundance of spp with requirement for movement between reaches or fish habitat segments | 1.0 | |
| | Response in terms of distribution/abundance of spp with requirement for movement within reach or fish habitat segment | 1.0 | |
| INTRODUCED SPECIES METRICS | The impact/potential impact of introduced competing/predaceous spp? | 0.5 | 64.7 |
| | How widespread (frequency of occurrence) are introduced competing/predaceous spp? | 0.5 | |
| | The impact/potential impact of introduced habitat modifying spp? | 1.0 | |
| | How widespread (frequency of occurrence) are habitat modifying spp? | 1.0 | |
| **FRAI SCORE (%)** | | **68.8** | |
| **FRAI CATEGORY** | | **C** | |
| **FRAI CATEGORY DESCRIPTION** | | **Moderately Modified** | |

**Table 13-3: Fish Response Assessment Index (FRAI) results for sub-quaternary reach B11C-1449 (upper Steenkoolspruit reach).**

| METRIC GROUP | METRIC | *RATING (CHANGE) | METRIC GROUP WEIGHT (%) |
|---|---|---|---|
| VELOCITY-DEPTH CLASSES METRICS | Response of species with high to very high preference for FAST-DEEP conditions | 0.0 | 95.6 |
| | Response of species with high to very high preference for FAST-SHALLOW conditions | 0.0 | |
| | Response of species with high to very high preference for SLOW-DEEP conditions | -1.0 | |
| | Response of species with high to very high preference for SLOW-SHALLOW conditions | -1.0 | |
| COVER METRICS | Response of species with a very high to high preference for overhanging vegetation | -1.0 | 100 |
| | Response of species with a very high to high preference for undercut banks and root wads | -2.0 | |
| | Response of species with a high to very high preference for a particular substrate type | -4.0 | |
| | Response of species with a high to very high preference for instream vegetation | 0.0 | |
| | Response of species with a very high to high preference for the water column | 0.0 | |
| FLOW DEPENDANCE METRICS | Response of species intolerant of no-flow conditions | 0.0 | 77.9 |
| | Response of species moderately intolerant of no-flow conditions | -4.0 | |
| | Response of species moderately tolerant of no-flow conditions | 0.0 | |
| | Response of species tolerant of no-flow conditions | 0.0 | |
| PHYSICO-CHEMICAL METRICS | Response of species intolerant of modified physico-chemical conditions | 0.0 | 63.2 |
| | Response of species moderately intolerant of modified physico-chemical conditions | -4.0 | |
| | Response of species moderately tolerant of modified physico-chemical conditions | -1.0 | |
| | Response of species tolerant of modified physico-chemical conditions | 0.0 | |
| MIGRATION METRICS | Response in terms of distribution/abundance of spp with catchment scale movements | | 51.5 |
| | Response in terms of distribution/abundance of spp with requirement for movement between reaches or fish habitat segments | 1.0 | |
| | Response in terms of distribution/abundance of spp with requirement for movement within reach or fish habitat segment | 1.0 | |
| INTRODUCED SPECIES METRICS | The impact/potential impact of introduced competing/predaceous spp? | 0.5 | 64.7 |
| | How widespread (frequency of occurrence) are introduced competing/predaceous spp? | 0.5 | |
| | The impact/potential impact of introduced habitat modifying spp? | 1.0 | |
| | How widespread (frequency of occurrence) are habitat modifying spp? | 1.0 | |
| **FRAI SCORE (%)** | | **81.1** | |
| **FRAI CATEGORY** | | **B/C** | |
| **FRAI CATEGORY DESCRIPTION** | | **Largely Natural/Moderately Modified** | |

**Table 13-4: Fish Response Assessment Index (FRAI) results for sub-quaternary reach B11D-1435 (Steenkoolspruit reach, downstream of the confluence with the Piekespruit).**

| METRIC GROUP | METRIC | *RATING (CHANGE) | METRIC GROUP WEIGHT (%) |
|---|---|---|---|
| VELOCITY-DEPTH CLASSES METRICS | Response of species with high to very high preference for FAST-DEEP conditions | -5.0 | 95.6 |
| | Response of species with high to very high preference for FAST-SHALLOW conditions | -5.0 | |
| | Response of species with high to very high preference for SLOW-DEEP conditions | -3.0 | |
| | Response of species with high to very high preference for SLOW-SHALLOW conditions | -3.0 | |
| COVER METRICS | Response of species with a very high to high preference for overhanging vegetation | -3.0 | 100 |
| | Response of species with a very high to high preference for undercut banks and root wads | -4.0 | |
| | Response of species with a high to very high preference for a particular substrate type | -5.0 | |
| | Response of species with a high to very high preference for instream vegetation | -2.0 | |
| | Response of species with a very high to high preference for the water column | -3.0 | |
| FLOW DEPENDANCE METRICS | Response of species intolerant of no-flow conditions | 0.0 | 77.9 |
| | Response of species moderately intolerant of no-flow conditions | -5.0 | |
| | Response of species moderately tolerant of no-flow conditions | -3.0 | |
| | Response of species tolerant of no-flow conditions | -2.0 | |
| PHYSICO-CHEMICAL METRICS | Response of species intolerant of modified physico-chemical conditions | 0.0 | 63.2 |
| | Response of species moderately intolerant of modified physico-chemical conditions | -5.0 | |
| | Response of species moderately tolerant of modified physico-chemical conditions | -5.0 | |
| | Response of species tolerant of modified physico-chemical conditions | -2.0 | |
| MIGRATION METRICS | Response in terms of distribution/abundance of spp with catchment scale movements | | 51.5 |
| | Response in terms of distribution/abundance of spp with requirement for movement between reaches or fish habitat segments | 2.0 | |
| | Response in terms of distribution/abundance of spp with requirement for movement within reach or fish habitat segment | 1.0 | |
| INTRODUCED SPECIES METRICS | The impact/potential impact of introduced competing/predaceous spp? | 3.0 | 64.7 |
| | How widespread (frequency of occurrence) are introduced competing/predaceous spp? | 3.0 | |
| | The impact/potential impact of introduced habitat modifying spp? | 3.0 | |
| | How widespread (frequency of occurrence) are habitat modifying spp? | 3.0 | |
| **FRAI SCORE (%)** | | **35.2** | |
| **FRAI CATEGORY** | | **E** | |
| **FRAI CATEGORY DESCRIPTION** | | **Seriously Modified** | |

**Table 13-5: Fish Response Assessment Index (FRAI) results for sub-quaternary reach B11D-1366 (Steenkoolspruit downstream reach).**

| METRIC GROUP | METRIC | *RATING (CHANGE) | METRIC GROUP WEIGHT (%) |
|---|---|---|---|
| VELOCITY-DEPTH CLASSES METRICS | Response of species with high to very high preference for FAST-DEEP conditions | -5.0 | 95.6 |
| | Response of species with high to very high preference for FAST-SHALLOW conditions | -5.0 | |
| | Response of species with high to very high preference for SLOW-DEEP conditions | -4.0 | |
| | Response of species with high to very high preference for SLOW-SHALLOW conditions | -3.0 | |
| COVER METRICS | Response of species with a very high to high preference for overhanging vegetation | -3.0 | 100 |
| | Response of species with a very high to high preference for undercut banks and root wads | -2.0 | |
| | Response of species with a high to very high preference for a particular substrate type | -5.0 | |
| | Response of species with a high to very high preference for instream vegetation | -3.0 | |
| | Response of species with a very high to high preference for the water column | -4.0 | |
| FLOW DEPENDANCE METRICS | Response of species intolerant of no-flow conditions | 0.0 | 77.9 |
| | Response of species moderately intolerant of no-flow conditions | -5.0 | |
| | Response of species moderately tolerant of no-flow conditions | -4.0 | |
| | Response of species tolerant of no-flow conditions | -1.0 | |
| PHYSICO-CHEMICAL METRICS | Response of species intolerant of modified physico-chemical conditions | 0.0 | 63.2 |
| | Response of species moderately intolerant of modified physico-chemical conditions | -5.0 | |
| | Response of species moderately tolerant of modified physico-chemical conditions | -5.0 | |
| | Response of species tolerant of modified physico-chemical conditions | -2.0 | |
| MIGRATION METRICS | Response in terms of distribution/abundance of spp with catchment scale movements | | 51.5 |
| | Response in terms of distribution/abundance of spp with requirement for movement between reaches or fish habitat segments | 2.0 | |
| | Response in terms of distribution/abundance of spp with requirement for movement within reach or fish habitat segment | 1.0 | |
| INTRODUCED SPECIES METRICS | The impact/potential impact of introduced competing/predaceous spp? | 3.0 | 64.7 |
| | How widespread (frequency of occurrence) are introduced competing/predaceous spp? | 3.0 | |
| | The impact/potential impact of introduced habitat modifying spp? | 3.0 | |
| | How widespread (frequency of occurrence) are habitat modifying spp? | 3.0 | |
| **FRAI SCORE (%)** | | **32.0** | |
| **FRAI CATEGORY** | | **E** | |
| **FRAI CATEGORY DESCRIPTION** | | **Seriously Modified** | |