Watercourse ecological sensitivity classification as a management framework to ameliorate pipeline construction impacts associated with the Ambatovy project

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Abstract

The slurry pipeline (SPPL) constructed from the Ambatovy mine (near the town of Moramanga) and the pressure acid leach plant (near the town of Toamasina) traverses the catchments of five river systems (Rianila, Iaroka, Sahanavo, Morongolo, and Ivondro) and could affect approximately 420 watercourses. Before construction activities, an aquatic ecological framework was designed to guide mitigation efforts in order to minimize the effect of possible construction impacts on the ecological integrity of these watercourses. The outcome of these analyses showed that 49 watercourses were classified as of high ecological sensitivity, 76 of moderate ecological sensitivity, and 295 of low ecological sensitivity. The watercourses classified as of high ecological sensitivity, had a very high likelihood of supporting endemic fish and maintain a high to very high biotic integrity with limited anthropogenic modifications. The watercourses classified as moderately sensitive suffered from more severe anthropogenic modifications but still maintained a fairly high biotic integrity. These ecologically sensitive conditions (high biotic integrity and likely presence of endemic fish) were generally confined to the lower order headwater sections of watercourses, which were therefore identified as the watercourses that would require the most stringent impact control and mitigation measures associated with the construction of the pipeline.

Keywords: Madagascar, watercourse ecological sensitivity, environmental effects monitoring, pipeline impact assessment, rapid biological assessment, habitat integrity, endemic fish

Résumé détaillé

Le pipeline supposé comme étant un lien entre la mine de nickel et de cobalt d'Ambatovy (près de la ville de Moramanga), à Madagascar, et l'usine de lixiviation acide (près de la ville de Toamasina) couvrira au moins cinq bassins versants différents dont Rianila, Iaroka, Sahanavo, Morongolo et Ivondro. Il pourrait affecter approximativement 420 cours d'eau. Etudier une à une tous ces points de franchissement des cours d'eau sera impossible, il faut trouver une méthode scientifique permettant de sélectionner quelques unes qui sont les plus importantes et représentatives. C'est le but de cette étude. Elle vise à prioriser ces écosystèmes aquatiques selon leurs sensibilités ; L'objectif global du travail est par conséquent d'évaluer la sensibilité écologique des cours d'eau et de concevoir une structure permettant d'améliorer les actions de franchissement afin de faciliter la mise en conformité des travaux de construction avec la politique zéro perte en espèce du projet minier d'Ambatovy. Le système de classification « ordre des cours d'eau » et de leurs pentes respectives en combinant avec l'intégrité écologique des régions ripariennes ont été utilisés pour atteindre cet objectif. Ces informations sont obtenues par : une carte topographique élaborée par le « Foibe Taontsarin'i Madagasikara » (FTM) a une échelle de 1 : 100000 et des images prisent par le satellite Lidar avec une précision de 2 m. Le résultat du travail a montré qu'un total de 40 cours d'eau été classé comme de haute sensibilité écologique, 70 de sensibilité écologique modérée et 348 de sensibilité écologique basse. Les cours d'eau classés comme de haute sensibilité écologique ont un habitat intact et ne présentent aucune trace d'impact anthropique,

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ils sont forts probables d'héberger une faune aquatique endémique très vulnérable. Ces conditions écologiques sensibles se rencontrent surtout dans les biefs supérieurs des cours d'eau, ou région source, et ont été identifiées par conséquent comme des écosystèmes qui exigeraient le contrôle de l'impact le plus strict et des mesures de mitigation. Apres les travaux sur le terrain, l'acuité des prédilections est de 63% ; la sensibilité de 12% des points d'eau ont été surestime ; par contre les 25% restantes sont plus sensible que prévues. Les erreurs ont été dues aux manques d'information concernant : la structure ichtyologique des biefs inférieurs des grands cours d'eau de Madagascar ; la distribution des espèces exotiques et la biologie et écologie des poissons endémiques. Toutefois le résultat est plus que satisfaisant, il a vraiment facilité la sélection des cours d'eau qui ont été suivi pendant la construction.

Mots clés: Madagascar, sensibilité écologique des cours d'eau, suivi des effets environnementaux, évaluation de l'impact de pipeline, inventaire biologique rapide, intégrité de l'habitat, poissons endémiques

Introduction

The ore slurry pipeline constructed to link the Ambatovy nickel and cobalt mine (near the town of Moramanga) with the pressure acid leach plant (near the town of Toamasina) traverses the catchments of five river systems (Rianila, Iaroka, Sahanavo, Morongolo, and Ivondro; Figure 1). Along this route, approximately 420 watercourses were affected where the pipeline crosses natural drainage systems. The 220 km steel pipeline with a 600 mm outside diameter and a wall thickness of 9.5 mm is buried over its entire length (SNC Lavalin & PSI, 2008). This was accomplished at stream crossings by trenching through the rivers, lowering-in the pipe, and then backfilling of trench. Horizontal drilling was the preferred crossing method underneath some of the larger rivers, where trenching was not practical. Construction activities included vegetation clearing of a 50 m band referred to as the 'right of way' along the entire centerline of the pipe. Earthworks were confined to between 15 and 25 m within the right of way. The construction of such infrastructure is bound to have negative impacts on the aquatic ecosystem through which it is routed (Levesque & Dube, 2007) and a framework was therefore required to guide mitigation efforts in order to minimize construction impacts on the ecological integrity of the watercourses.

This article presents the approach used to design such an ecological framework, which was based on the expected ecological sensitivities of watercourses associated with the pipeline in order to govern construction activities and as such facilitate compliance with the Ambatovy mining project's biodiversity policy of "zero species loss" (Biodiversity Management Plan, 2007).

Methods and techniques

Literature Search

Background data were collected using standard internet search engines to obtain published and unpublished references that would provide details on pipeline construction techniques and particular attention was given to ecologically sensitive watercourses. Specifications of technical aspects of the pipeline, the right of way, centerline alignment, and all pipeline crossings through water courses were obtained from the relevant engineers.

Watercourse classification

Watercourse characterization

The characterization of the drainage systems associated with the pipeline watercourse crossings was based on an engineering database and was conducted on a desktop computer. The watercourse crossings along the pipeline route were overlaid onto Lidar imagery (UTM 39S), obtained for the Ambatovy project, using the ArcMap/View 3.2a GIS software package. The watercourse crossings were divided into channeled and un-channeled watercourses with the former being where surface water flow is clearly confined to a well defined channel and the latter being where water flow, both surface and sub-surface, is not confined to well defined channels. A Lidar digital elevation model (2 m contour interval), in association with the FTM (*Foibe Toatsarin-tany Malagasy*) hydro-map (1/100.000 scale, UTM 39S) were then used to quantify stream order, stream gradient, and the expected ecological integrity for all channeled water courses. Stream order was quantified using the Strahler (1952) stream order classification method starting with a first order stream as the most upstream drainage line (normally non-perennial) and increasing in order in a downstream direction at the confluence with a stream of at least the same order e.g. 1+1 = 2; 2+2 = 3; 3+3 = 4 etc. The stream gradient was calculated focusing on the midpoint of the pipeline right of way across the stream and the distance between the closest upstream and downstream contour lines

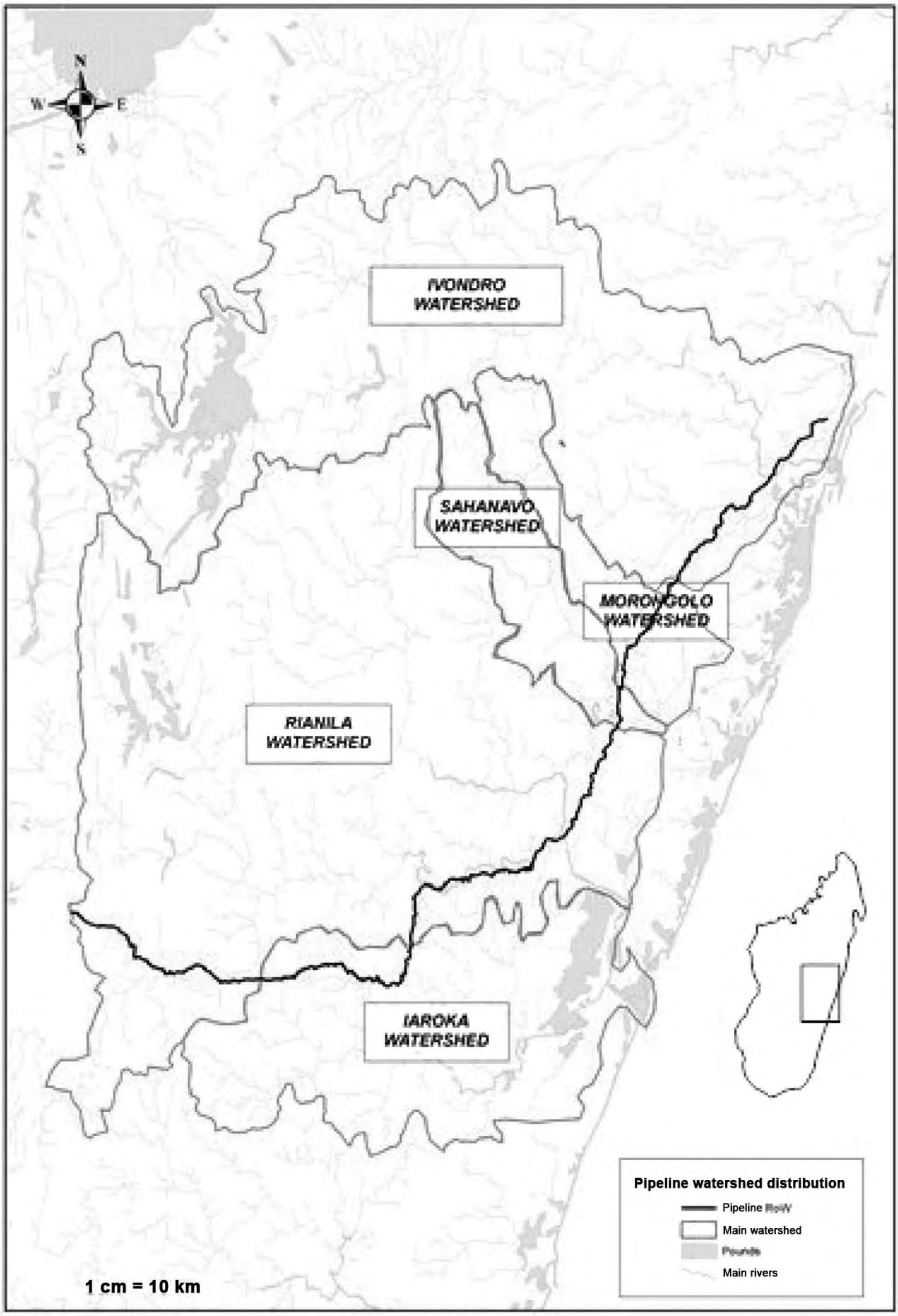

Figure 1. Map depicting the right of way for the Ambatovy slurry pipeline from the mine to the processing plant in Toamasina. The locations of the five watersheds are also indicated.

along the stream as recorded from the Lidar digital elevation model (accuracy of 2 m elevation intervals). Ecological integrity was characterized for each pipeline crossing point, for a radius of approximately 50 m around the crossing mid point, based on a visual assessment (using Lidar imagery) of the level of alteration to the natural vegetation around the point.

Five ecological integrity classes (Kleynhans, 1996) were used as the basis to assign site-specific integrity:

- Class 1 - the natural in-stream and riparian habitat remained fully intact with no visible signs of human impact;
- Class 2 - the natural in-stream and riparian habitat functioning remained fully intact but with limited signs of human impact;
- Class 3 - the natural in-stream and riparian habitat partially damaged but likely to support some sensitive biotic assemblages. Large human impacts affect the site;
- Class 4 - the natural in-stream and riparian habitat largely damaged with tolerant species assemblages remaining;
- Class 5 - the natural in-stream and riparian habitat have been completely lost.

Watercourse sensitivity classification

Work conducted related to the characterization of the watercourses associated with the pipeline was further assessed with regards to the ecological sensitivity for each crossing. This was done based on an understanding of how the ecological functioning of watercourses may be altered in relation to the pipeline impacts. Channeled and unchanneled watercourses were treated in a different manner in order to take account of the respective differences in ecological functioning. Ecological integrity using a similar classification model as for channeled watercourses was the only parameter characterized for all un-channeled watercourses.

Channeled watercourses

The consolidated background information and the pre-established criteria of stream gradient, integrity and stream order of the applicable watersheds were used to design a decision making framework to facilitate the classification of the ecological sensitivity of watercourses at pipeline crossings. The classification was based on the possible presence of endemic fish where the higher the likelihood of their presence, the more sensitive the watercourse. The decision-making framework was designed to group the different watercourses into five classes based on the integrity classes applied by Kleynhans (1996). These five classes were then regrouped into three ecological sensitivity classes to simplify the outcome.

1) For watercourses with a high sensitivity to impacts - the fish assemblage is expected to be dominated by endemic fish;
2) For watercourses with a moderate sensitivity to impacts - the fish assemblage is expected to be of a more or less equal diversity between endemic and exotic fish; and
3) For watercourses with a low sensitivity to impacts - the fish assemblage is likely dominated by exotic fish.

Unchanneled watercourses

The unchanneled watercourses were classified into one of three sensitivity classes based on a visual assessment (from Lidar imagery) of the ecological integrity at the crossing:

1) High sensitivity to impacts – unchanneled water courses with a high ecological integrity and thus functioning;
2) Moderate sensitivity to impacts – unchanneled water courses with a moderate ecological integrity and thus functioning; and
3) Low sensitivity to impacts – unchanneled water courses with a low ecological integrity and thus functioning.

Field verification

Sites for field verification were selected along the pipeline route using Lidar imagery as well as the preliminary sensitivity assessment to represent watercourse crossings identified from the desktop characterization as of a high, moderate, and low ecological sensitivity. Sixteen sites were surveyed during July to September 2007 by three field teams from the Universities of Antananarivo and Toamasina. These field teams where trained in relevant survey techniques to ensure the standardization of survey efforts. The main aim of the field survey was to collect relevant information for an evaluation of the accuracy of the desktop sensitivity classification. The following parameters were assessed up and downstream from each watercourse crossing:

1) The presence of endemic and exotic fish using electric fishing techniques. Whole specimens, as well as genetic tissue samples, were

collected and preserved in formalin and ethanol, respectively. These voucher specimens are housed in the University of Antananarivo, the Ambatovy holding facility, and eventually the South African Institute for Aquatic Diversity;

2) The biotic integrity of each site was evaluated using rapid biological assessment techniques focusing on aquatic macro-invertebrates as indicators of impairment (Dickens & Graham, 2002);
3) Using portable field equipment, water quality at each site was assessed for the following parameters: pH, electrical conductivity, temperature, and turbidity.

The results from the field surveys were presented as percentages of endemic to exotic fish species and compared with the predicted assemblages from the desktop assessment.

Results

Watercourse classification

The outcome of the desktop classification showed that the Ambatovy pipeline crosses 420 watercourses of which 311 were channeled and 109 unchanneled. Assessments of the ecological sensitivity of these sites showed that 49 watercourses were classified as high, 76 moderate, and 295 low. The watercourses classified as of high ecological sensitivity were expected to support endemic fish and be biotically intact. These ecologically sensitive conditions were generally confined to the lower order headwater sections of watercourses. The majority of the high sensitivity watercourses are situated along the first part of the pipeline in close proximity to the Ambatovy mine site. Watercourses classified as of moderate ecological sensitivity are distributed throughout the pipeline route and generally associated with the higher order streams, which are more degraded as a result of habitat alterations, as well as the presence of exotic fish species. The watercourses classified as of low ecological sensitivity are more prevalent in the lower section of the pipeline and often in areas of higher local human population densities. These watercourses are generally dominated by exotic fish and are of a poor biotic integrity.

Field verification

The summarized data from the field survey are presented in Table 1. From these results, it is evident that 63% of the preliminary sensitivity rankings were predicted correctly, 12% were predicted to be less sensitive than recorded, and the remaining 25% were predicted to be more sensitive than recorded. These results were then used to amend the sensitivity rankings, specifically for the larger rivers, which were generally predicted to be less sensitive (more exotic fish species than endemic) than recorded in the field.

Discussion

A decision-making framework was designed to classify the ecological sensitivity of watercourses associated with the pipeline. This framework was based on the distribution of endemic fish species, which were assumed to be governed by gradient, stream order (Beecher *et al.*, 1988), and habitat integrity (Irwin *et al.*, 2010). Gradients steeper than 1:30 generally were assumed not to support fish, except for cosmopolitan species like anguillids (Rall *et al.*, 2008). Fish species distributions are also governed, albeit to a lesser extent, by watercourse order (Beecher *et al.*, 1988) and seasonal streams of first and second order were therefore assumed not to support fish. The overall habitat integrity of the watercourse also plays a role in the distribution of fish species, where streams passing through human disturbed habitat are expected to harbor more tolerant generalist species (Irwin *et al.*, 2010). The overall accuracy of the ecological sensitivity classification conducted for the Ambatovy pipeline was further affected by:

1) The accuracy of the 1/100.000 FTM maps used for the study, which was not regarded as high;
2) The lack of Lidar imagery across larger sections of the catchments affected by the pipeline preventing interpretations along the same map template; and
3) The presence of exotic fish, which cannot be predicted using desktop level modeling without detailed fish surveys as the distribution patterns depend on introduction of exotics, subsequent migration, and the presence of migration barriers.

The presence of exotic fish was therefore assumed to be correlated with the level of degradation within a river (more degraded rivers are more likely to be dominated by exotics).

The inaccurate predictions of the desktop classification, 37% of sites verified in the field, can be ascribed to several factors:

1) The lack of information regarding the nature of fish assemblages in larger rivers, which seems to harbor a relatively higher diversity of endemic fish than expected. This is likely associated

Table 1. Summarized results comparing the outcome from the field survey in relation to predicted desktop ecological conditions for selected watercourses at specific kilometer points.

Kilometer points	TEST1	09+560	25+340	37+960	48+480	63+160	72+880	93+630	103+970	124+670	149+320	153+760	162+400	176+700	189+540	211+650
Number of fish species	2	5	3	5	2	3	4	5	7	8	5	3	5	5	9	8
Number of native fish species	0	1	0	2	1	1	2	1	2	4	1	1	4	3	5	5
Number of endemic fish species	1	2	0	2	1	1	2	3	3	4	1	1	1	1	3	3
Number of exotic fish species	1	2	3	1	0	1	0	1	2	0	3	1	0	1	1	0
Predicted sensitivity	mod	high	high	high	high	mod	high	mod	mod	low	low	mod	mod	low	mod	low
Confirmed sensitivity	mod	mod	low	high	high	mod	high	high	mod	high	low	mod	mod	mod	mod	high
Level of protection	accurate	over	over	accurate	accurate	accurate	accurate	under	accurate	under	accurate	accurate	accurate	under	accurate	under

with the greater assimilative capacity of the bigger rivers favoring endemic fish, which also means that the impact of the pipeline crossing over these rivers will be less significant than for smaller, lower order streams with a lower assimilative capacity;
2) The lack of information regarding the distribution of exotic species;
3) The lack of information regarding the habitat requirements of endemic fish species and;
4) The lack of information regarding the distribution of endemic fish across impact gradients.

Conclusion

The results generated from this work, clearly indicate that the developed ecological framework was adequate to ensure the design of conceptual watercourse crossing protocols, which would facilitate the protection of the aquatic ecology for approximately 75% (63 + 12) of the watercourses to be affected by the pipeline.

The sole application of the sensitivity assessment would, however, not ensure compliance with the Ambatovy biodiversity management plan commitments and it was recommended to the contractors that ecological surveys be conducted prior to the construction of every single watercourse crossing to ensure the implementation of adequate mitigation measures relevant to the specific ecological sensitivity of the stream to be crossed.

Recommendations

1) To confirm the actual ecological sensitivity of all watercourses prior to any construction in order to ensure the application of the appropriate protocols;
2) To monitor construction impacts using fish and macro-invertebrate assemblages as indicators to assess mitigation performance and compliance with benchmarks; and
3) To implement appropriate restoration measures when and if required.

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References

Beecher, H. A., Dott, E. R. & Fernau, R. F. 1988. Fish species richness and stream order in Washington State streams. *Environmental Biology of Fishes*, 22: 193-209.

Biodiversity Management Plan. 2007. Biodiversity management plan. The Ambatovy nickel project (AMSA/DMSA) specific environmental management plan. Unpublished report submitted to ONE, March 2007.

Dickens, C. W. S & Graham, P. M. 2002. The South African Scoring System (SASS). Version 5. Rapid bio-assessment method for rivers. *African Journal of Aquatic Sciences*, 27: 1-10.

Irwin, M. T., Wright, P. C., Birkinshaw, C., Fisher, B. L., Gardner, C. J., Glos, J. Goodman, S. M., Loiselle, P., Rabeson, P., Raharison, J., Raherilalao, M. J., Rakotondravony, D., Raselimanana, A., Ratsimbazafy, J., Sparks, J. S., Wilmé, L. & Ganzhorn, J. U. 2010. Patterns of species change in anthropogenically disturbed forests of Madagascar. *Biological Conservation* doi:10.1016/j.biocon.2010.01.023.

Kleynhans, C. J. 1996. A qualitative procedure for the assessment of the habitat integrity status of the Luvuvhu River (Limpopo system, South Africa) *Journal of Aquatic Ecosystem Health*, 5: 41-54.

Levesque, L. M. & Dube, M. G. 2007. Review of the effects of in-stream pipeline crossing construction on aquatic ecosystems and examination of Canadian methodologies for impact assessment. *Environmental Monitoring and Assessment*, 132: 395-409.

Rall, J. L., Aken, W. R., Swartz, E., Ravelomanana, T., Rasoloniaina, J., Ndriantsoa, H. S. & Ratsoavina, F. M. 2008. Fish extinction avoidance program for Ambatovy mine. Unpublished report submitted to Ambatovy project, pp 30.

SNC Lavalin & PSI. 2008. Technical specification pipeline construction. Ambatovy project. Unpublished report, specification number: 334488-2440-46EF-2001-1.

Strahler, A. N. 1952. Hypsometric (area-altitude) analysis of erosional topography. *Geological Society American Bulletin,* 63*:* 1117–1142.