Abstract

Appendix A. Pollution of environment (land, water and atmosphere) has increased rapidly since the onset of the industrial revolution. Population increase has placed much strain on the environment as have large-scale logging, mining and other commercial activities. Mining earns valuable foreign exchange but pollutes the environment, especially the water and soil through exposure to its discharge (treated or otherwise). Toxic heavy metals are present in this discharge and thus contaminate the soil, vegetation, water systems and marine life. There is a need to minimise or eliminate these heavy metals from the effluent as well as the mine site after closure. One eco-friendly and sustainable mode of toxic heavy metal removal is phytoremediation. This review outlines what phytoremediation is, the classes of phytoremediation, the pros and cons of phytoremediation, its application and its relevance and applicability to the PNG situation. Suggestions will be made as to the most suitable plants for selected disused sites in PNG.

Keywords:

1. Introduction

Papua New Guinea (PNG) has experienced mining activities since 1888 (Corbett, 2005). Despite its well-known and rich biodiversity and rainforest, the mining activities are booming with a total of almost 22 mining that are currently operating, others under exploration and some have been closed already. The risk of environmental pollutions is very high and is currently being growing despite mining companies control and regulatory monitoring on the environment. Evidence can be seen from the big Ok Tedi mining company waste deposits downstream and current Lihir gold mining company waste deposits using Deep Sea Tailings Placement (DSTP) into Pacific Ocean.
The mining companies and PNG government are doing least they can yet having minimal control over waste disposal into the surrounding environment. The diverse fauna and flora including marine aquatic ecosystem will gradually vanish without considering a better remedial technique in-place to cater for such toxic waste disposals from mining activities in PNG.

Phytoremediation technique is one of the remedial hopes for environment left which PNG is yet to realize and remediating loss created on their environment by mining companies operations. Despite, rehabilitation of close mine or wasteland sites by using selective plants for nitrogen fixations, soil covering, local plants re-growth and increasing biomass, phytoremediation technique plays vital role both absorbing of pollutants and restoring soil nutrients and fertility. A case study of closed mine environment at Namie mine in Wau district of Morobe province, PNG has been underway to investigate the efficiency of local plant species capable of remediating heavy metals (Cd, Cu, Fe, Hg, Pb, Zn) in mine site after 70 years of mining operations. This paper aims at discussing how phytoremediation technique can suitably fits into PNG and why this green technology should be considered as an alternative method of environment remedial technique for mine disused site, industrial waste disposal site, wasteland and general polluted sites.

1.1. Sources of Heavy Metals in the Environment

Generally, heavy metals present naturally in the environment or are generated as man-made processes and are considered as by-products (Harvey, 2011). Under normal conditions some are known as pollutants and return back into the environment. The natural environment processes have the ability to assimilate some pollutants and correct most imbalances if given enough time. Heavy metals can also concentrate out through natural occurrence or by disposal of municipal and industrial waste, sediments from waste water treatment plant, leachate from solid water treatment plant, mining effluents, some from industry, agricultural, urban, landfills, utility stations, motor pools, and fleet maintenance facilities landfills, utility stations, motor pools and fleet maintenance facilities, etc (WQD, 2003).

1.2. Absorption of Heavy Metals into Plants

The process of absorption and transformation of heavy metals into plant system depend very much on their solubility and complexity. Basically, plants extract and accumulate metals from soil solution. Before the metal can move from the soil solution into the plant, it must pass the surface of the root. This can either be movement of metal ions passing through the porous cell wall of the root cells, by which metal ions move symplastically through the cells of the root. This latter process requires that the metal ions traverse the plasmalemma, a selectively permeable barrier that surrounds cells (Pilon-Smits, 2005). Special plant membrane proteins recognize the chemical structure of essential metals; these proteins bind the metals and are then ready for uptake and transport. Numerous protein transporters exist in plants. For example, the model plant thale cress (A. thaliana) contains 150 different cation transporters (Axelsen and Palmgren, 2001) and even more than one transporter for some metals (Hawkesford, 2003). Some of the essential, nonessential and toxic metals, however, are analogous in chemical structure so that these proteins regard them as the same. For example arsenate is taken up by P transporters. Abedin et al. (2002) studied the uptake kinetics of as species, arsenite and arsenate, in rice plants and found that arsenate uptake was strongly suppressed in the presence of arsenite. Clarkson and Luttge (1989) reported that Cu and Zn, Ni and Cd compete for the same membrane carriers. For root to shoot transport these elements are transported via the vascular system to the above-soil biomass (shoots). The shoots are harvested, incinerated to reduce volume, disposed of as hazardous waste, or precious metals can be recycled (phytomining). Different chelators may be involved in the translocation of metal cations through the xylem, such as organic acid chelators [malate, citrate, histidine (Salt et al., 1995b; von Wiren et al., 1999), or nicotianamine (Stephen et al., 1996; von Wiren et al.1999). Since the metal is complexed within a chelate it can be translocated upwards in the xylem without being adsorbed by the high cation exchange capacity of the xylem (von Wiren et al., 1999).

1.3. Conventional Techniques Used in Treating Heavy Metal Pollution

There are in fact conventional or traditional remediation techniques involve in treating heavy metals in the environment. They are such as land filling and leaching, excavation, burial or soil washing and soil flushing (Salt,
2000). However these approaches are cost intensive, not economically viable, intrusive in nature and cause soil degradation, not bonafide decontamination measures but a temporary evasion of problem, destabilize natural ecosystem and aesthetically unacceptable. Other method is microbial measures. This method involves decontamination of polluted land through application of immobilized microbial enzymes. This involves the use of resistant microorganisms like fungi, bacteria and vesicular arbuscular mycorrhizae. A.G. Khan, C. Kuek, T.M. (Chaudhry, 2000). These microbial approaches are ecological and economically sound but physical removal/cleaning up of the contaminants does not occur as contaminants remain in the soil system. Chemical extraction procedures have been suggested but they are not cost effective. Therefore, these constraints have forced the researchers to use plants for cleaning up their own support system (pollution) and that is where phytoremediation technique was developed.

| Mechanism                  | Process Goal                      | Media                  | Contaminants                  | Plants                                      | Status                  |
|---------------------------|-----------------------------------|------------------------|-------------------------------|---------------------------------------------|-------------------------|
| Phytoextraction            | Contaminant extraction and capture.| Soil, sediment sludges  | Metals: Ag, Cd, Co, Cr, Cu, Hg, Mn, Ni, Pb, Zn, Radioisotopes: ^90^Sr, ^137^Cs | Indian mustard, pennycress, abyssum sunflower, hybrid | Field applications     |
| Rhizofiltration            | Contaminant extraction and capture.| Groundwater, surface water | Metals, radionuclides       | Sunflowers, Indian mustard, water hyacinth | Laboratory and pilot-scale |
| Phytostabilization         | Contaminant containment            | Soil, sediment sludges  | As, Cd, Cr, Co, Ha, Pb, Zn   | Indian mustard, hybrid poplar, grasses      | Field application       |
| Rhizodegradation           | Contaminant destruction            | Soil, sediment sludges, ground water, | Organic compounds (TPH, PAHs, petroleum, chlorinated solvents, PCBs) | Rad mulberry, grasses, hybrid poplar, castail, tea | Field application       |
| Phytodegradation           | Contaminant destruction            | Soil, sediment sludges, ground & surface water | Organic compounds (cholorinated solvents, phenols, herbicides) | Algae, astoweet, hybrid poplar, black willow, bald cypress | Field application       |
| Phytovolatilization        | Contaminant extraction from media and release. | Groundwater, soil sediment, sludges | Chlorinated solvents, some inorganics (Ca, Mg, and Al) | Poplar, ash, black locust, Indian mustard | Field demonstration    |
| Hydraulic control (plume control) | Contaminant degradation or containment | Groundwater, surface water | Water-soluble organics and inorganics | Hybrid poplar, cottonwood, willow | Laboratory and field application |
| Vegetative cover (evapotranspiration cover) | Contaminant containment, erosion control | Soil, sludge, sediments | Organic and inorganic compounds | Poplar, grasses | Field demonstration |
| Riparian corridor (non-point source control) | Contaminant destruction | Surface water, groundwater | Water-soluble organics and inorganics | Poplar | Field application |

Source: Nancy, 2000 - EPA.
2. Phytoremediation: Technologies and Applications

Phytoremediation can be defined as the use of plants to remove pollutants from the environment. The principle of phytoremediation is that, plant roots either break the contaminant down in the soil or absorb the contaminant, storing it in the stems and leaves of the plant. It can be effectively carried out for the removal of contaminants from commercial waste disposal/dumping site, industries, agriculture and mining sites (Adams, 2000). There are different phytoremediation techniques available as shown in Table 1. All these phytoremediation techniques use selective plants roots to either breaking the contaminants down in the soil or absorbing the contaminants up, whilst storing it in the stems and leaves of the plants (Adams, 2000). This process is applicable in the field of agriculture for contaminants removal and land preparation for cultivation, or wasteland site remediation especially from commercial and industrial zones or for mine wasteland site remediation and environment restoration. It can be effectively carried out for remediation of heavy metals, petroleum hydrocarbons, chlorinated solvents, pesticides, radio nuclides, explosives and excess nutrients (McCutcheon, 2002).

2.1. Pro’s and Con’s of Phytoremediation

As with most new and green technologies, phytoremediation has its pros and cons. Contaminant solubility may be increased leading to greater environmental damage and the possibility of leaching (Phytoremediation, ??). The low cost of phytoremediation (up to 1000 × cheaper than excavation and reburial) is the main advantage. However many of the pros and cons of phytoremediation applications depend greatly on the location of the polluted site, the contaminants in question, and the phytoremediation technique applied (Phytoremediation, ??). Table 2 shows the disadvantages and advantages of phytoremediation as compared to classical remediation.
3. Phytoremediation and Rehabilitation Mine Environments in PNG

There has been a long complex history of environmental issues associated with mining in PNG. Most of these relate to the poisoning of waterways by riverine tailings disposal. Riverine tailings disposal causes sedimentation; and mercury, cyanide and other heavy metal contamination. More recently there has been a move into Submarine Tailings Disposal (STD) (MPI, 2008). The types of environmental pollutions and destructions have increased rapidly where mining operation is also a contributing factor to these problematic issues. There are guidelines and policies that governs mining operational act in PNG, such as environmental issues are subject for protection under PNG Environmental Planning Acts (EPA). The major goal of this legislation is to achieve uniform systems of environmental management. It is also mandatory for mining companies in PNG to incorporate mine closure plans as a prerequisite for the Special Mining Lease (SML) which paves the way for operations to commence. The mine closure plan may include revegetation and rehabilitation of the mined site as Department of Mines (2003) stipulates: “the areas of land affected by the mining project are rehabilitated and the land returned to environmentally sustainable conditions”. For example, WauNamie Mine site was revegetated by local experts from PNG Forestry Research Institute (PNGFRI) after the contract was awarded by Renisons and Goldfield Consolidated (RGC) company in 1999 (Pokana, 2005). However, with regard to PNG EPA and environmental management, phytoremediation technique is more suitable in the process of rehabilitation of environment or can be applied at waste disposal site to control and minimize toxic waste from spreading and destructing the environment. For instance, with the case of Misima, Porgera (Kogai dump site), Highlands Kainantu, Ok Tedi (rehabilitation plan) and WauNamie mine closure, have used a number of plant species for their mine site rehabilitation program. In addition, most of these species are legume plants (such as leucaena, acacia, serianthes, etc) which provide and improve soil nitrogen level with other soil nutrients for healthy plant growth, surface soil quality restoration, assist biodiversity and also improve microhabitat over time (Pokana, 2005).

| #  | Mine (Closure year) | Ore Type | Location | ALT (m a.s.l) | Mine Type | Status | Ext. Annual Output |
|----|---------------------|----------|----------|--------------|-----------|--------|-------------------|
| 1  | Namie mine (1993)   | Gold     | Wau, MP  | 1,619        | Open pit  | Closed and rehabilitation in progress for 19 years by PNGFRI | Insufficient data. |
| 2  | Misima mine (2004)  | Gold & silver | Misima, MBP | 9–40        | Open pit  | Rehabilitation in progress for 8 years by PNGDE. | 252,178 oz gold and 146,215,700 oz silver. |
| 3  | Highlands Kainantu (suspended 2006) | Gold | Kainantu, EHP | 1,600–1,900 | Underground | Under suspension | 19,308 oz gold. |
| 4  | Ok Tedi (close up plan) | Copper & gold | Star Mountain, WP | 2,000      | Open pit  | Working in progress for close up and rehabilitation plan. | 55, 437, 390 oz copper and 565, 9120 oz gold |
| 5  | Porgera (Kogai dump site) | Gold | Porgera, EP | 2,000–2,700 | Underground & open pit | Operating (rehabilitation on Kogai dump site) | 878,351 oz gold |

Source: (MPI, 2008), (PDAP, 2003). (Note: MP= Morobe province, MBP= Milne Bay province, EHP= Eastern Highlands province, EP= Enga province, PNGFRI=PNG, PNGDE=PNG Department of Environment & Conservation).
A case study in WauNamie Mine Site Rehabilitation has 46% of the trial tree species surviving through harsh condition to improve site adaptability like Albiziafalcataria, Leucaena Mexican, L. MacrophyllaBenth, Casuarina oligodon L. Johnson and Acacia angustissima (P. Mill) Kurtze (Pokana, 2005). This case study was conducted by J. Pokana and J. Paul who have found that despite the absence of mine closure plan policy; there were evidence of minimising soil erosion, increasing vegetation cover, top soil formation, increase in soil mineral nutrients, presence of microorganisms and resettling by locals (Pokana, 2005). This evidence confirms that the introduced species are mostly nitrogen fixation and are concentrating at improving top soil, vegetation and biodiversity (that includes microhabitat over time). However, the current selected phytoremediation species on site have being researched on their adaptability and natural survival capability over harsh and burden soil and environmental conditions. Their survival creates potential research study especially with regard to heavy metals absorption and soil stability. They are also adaptable both at very low altitude (coastal area) and at higher altitude (highland) especially in Morobe province of PNG. Moreover, all the process involve in the rehabilitation at the disused mine sites have been focusing mainly on re-vegetation with less concern being given to the presences and complete removal of toxic waste and how they can be minimized without causing long term effects on the environment.

For example, despite the rehabilitation and closure plan at Ok Tedi mining limited, there is still struggle with environmental impact of their tailing disposal downstream. Effects are enormous such as die-back, riverine tailing disposals and associated contaminations of downstream environment (MPI, 2008). Furthermore, a report by ABC Science confirms that there has been sulphur-laden mine waste building up and being exposed to oxygen at Ok Tedi (ABC Science, 2008). This may have potential effect of long-term toxicity of acid mine drainage. This is likely to happen as ore nature is porphyrites and skarn (i.e. copper ore) which has possibility of releasing sulphur. Find below is disused mines currently in PNG with information of mines operations (Table 3).

4. Status of Phytoremediation Remediation in PNG

The rehabilitation program at mine sites of PNG such as Misima, Porgera (Kogai dump site), WauNamie mine, Ok Tedi (close up and rehabilitation plan) are focusing generally on re-vegetation without removing and stabilising the core effects of mining such as those that can have long term effects through food chain and bioaccumulation process. Recently, at PNG University of Technology under the Environmental Research and Management Centre (ERMC) in collaboration with department of Mining Engineering, have made a great effort by putting up a research project into the field of phytochemical remediation where phytoremediation technique is applicable such as in mine closure sites. This research project is focusing at potential phytoremediation plant species at WauNamie mine closure and rehabilitation as to study specific and potential plant species with their efficiency and how they have contributed towards the rehabilitation process over eighteen (18) years of rehabilitation starting in 1993 by PNG Forestry Research Institute (PNGFRI) as rehabilitation program coordinators.

5. Methodology and Study Design Used in Preliminary Data Collection

The study was designed into two (2) phase. Phase one (1) was based on research study covering general environment of rehabilitated site and data collection. Phase two (2) was based on identifying potential phytoremediation species and also studying its efficiency in remediating the closed mine environment with regard to heavy metal contaminants. Data collected here are preliminary data and have been discussed as to observed heavy metal trends on site and possible local plant species that were active in absorbing heavy metals contaminants after mine closure.

5.1. Environmental Sampling

Samples were collected randomly from closed Namie mine site environment after nineteen (19) years of closure and rehabilitation. Standard methods of sampling were applied (see table below for methods applied). Total numbers of samples collected altogether were twenty six (26). These samples were collected and categorised into three (3) major components such as water, soil and garden food. Water samples were collected from creeks nearby and ponds which were developed after mine closure. Soil samples were randomly collected within the mine rehabilitated site whilst garden food samples were collected from gardens that were made by locals inside the mine rehabilitation
boundary. All environmental samples were labelled and packed tightly into esky with coolants and transported to Laboratory for analysis. Table 4 below shows information on samples collected from the field and their details.

| Mine Rehabilitate Site  | Cd    | Cu     | Fe     | Pb     | Hg     | Zn     |
|-------------------------|-------|--------|--------|--------|--------|--------|
| Creeks                  | 0.0086| 0.00902| 0.3464 | 0.00162| 0.0002 | 0.2356 |
| Ponds                   | 0.000333 | 0.009667| 0.128667| 0.0015 | 0.0002 | 0.0819 |
| Soils                   | 9.5143 | 39.2857 | 38.742.86 | 56     | 33.14290 | 249.5714 |
| Garden foods            | 0.005 | 9.25   | 57.5   | 0.01   | 0.001  | 17.4   |
| Control water sample    | 0.00001 | 0.0001 | 0.02   | 0.0001 | 0.0001 | 0.0029 |
| Control soil sample     | 3     | 20     | 21     | 25     | 0.66   | 10     |
| Control food sample     | 0.61  | 63     | 45     | 0.01   | 0.01   | 11     |

Note: 1) Soil and garden food concentration unit=μg/g = ppm, creeks & pond concentration unit=mg/L=ppm.
2) All results were obtained from PNG National Analysis Laboratory located at PNG University of Technology.

5.2. Sample Analysis

The elements of interest for these particular analyses were six (6) heavy metals and they are cadmium (Cd), copper (Cu), lead (Pb), iron (Fe), mercury (Hg) and zinc (Zn). All samples were analysed using inductive coupling plasma technique (ICP) while mercury analysis samples were analysed using cold vapour atomic absorption spectrophotometer (CVAAS) technique. The standard ICP method used was adopted from method number ID-206, “ICP analyses of metal/metalloid particulates from solder operations” (TERL, ??). The standard method used in analysing Hg in soil, water and foods (biological tissue) were adopted from Trace Element Research Laboratory (TERL) standard analytical method code number 003 for environmental sample preparation and TERL standard method code number 024 and 025 for CVAAS analysis (TERL, ??).

5.3. Results and Discussions

There are significantly high amount of heavy metals in soils as evidence from the average results of heavy metals as shown on the table 4 below. Other environmental aspect of mine such as creeks, ponds and garden foods shows less content of heavy metals. With comparison to the control samples, all sample results shows a minimal and stable results as compared except soil sample results. Overall, a further investigation on phytoextraction with selective plant species is necessary and the up-take of metal content from mine soil environment.

5.4. Identification of Potential Phytoremediation Species in Closed and Rehabilitated Namie Mine Environment

The identified potential plant species for phytoextraction is Piper anduncum, Brachiariareptans and Phragmiteskarka (pitpit). These are all local plant species that can adopt easily into the harsh conditions of bare infertile soil after mine closure. Obviously, after mine closure the soil nature is concentrated with heavy metals as evidence from environmental sample results as shown in table 4 above. A further sampling and analysis of these plant species is required to investigate their absorption rate and heavy metal content that were absorbed after mine closure.
6. Conclusions

It is a fast developing field, since last 10 years lots of field application were initiated all over the world. Sustainable and inexpensive process is available alternative to conventional remediation method. Phytoremediation is known to be economically cost benefit and helpful to environment that was once destroyed by mining activities, agriculture, logging, industries and is applicable to any chemical pollutants in the environment. It has significant benefits to human beings and surrounding ecosystem such as reviving land and soil nutrients availability, enabling re-growth of vegetation and wildlife to exist again. This green technology is suitable and highly recommended for Papua New Guinea case studies as to improve destruction caused and imposed on environment by mining and rising industries through this country. A preliminary data collection from rehabilitated Namie mine site has shown sufficient evidence of soil having high concentration of heavy metals. With that, a further investigative research and plan is underway at the Papua New Guinea University of Technology to study the phytoextraction process of locally selected plant species especially with their process and efficiency of phytoremediation at Namie mine of Wau district of Morobe Province of Papua New Guinea.

Acknowledgements

Firstly, many thanks to ERMC Director and my principle supervisor, Dr. Gabriel Arpa for introducing me to phytoremediation and for the permission for use of ERMC facilities and Mining Engineering department. Above all, I would like to make a very special thanks to my Creator.

References

1. ABC Science, Anna Salleh, Toxic time boom awaits Ok Tedi, Friday 5th September 2008, (2008).
2. Abedin MJ, Feldmann J, Meharg AA. Uptake kinetics of arsenic species in rice plants. Plant Physiol. 128: 1120-28, (2001).
3. A.G. Khan , C. Kuek, T.M. Chaudhry, C.S. Khoo, W.J. Hayes, “Role of plants, mycorrhizae and phytochelators in heavy metal contaminated land remediation”, Chemosphere 41, p. 197-207, (2000).
4. Axelsen, K.B. and Palmgren, M.G. Inventory of the superfamily of P-type ion pumps in Arabidopsis. Plant Physiol. 126: 696-706, (2001).
5. Clarkson DT, Luttge U. Mineral nutrition: divalent cations, transport and compartmentation. Progr. Bot. 51: 93-112, (1989).
6. Greg Corbett, The Geology and Mineral Potential of Papua New Guinea, p. 9-13, (2005).
7. Department of Mines, Independent State of Papua New Guinea, Public Discussion Paper, Mine Act 1992 – Mine Closure Issues, Konedobu, Port Moresby, Papua New Guinea, pp. 36, (2003).
8. Hawkesford, MJ. Transporter gene families in plants: the sulfate transporter gene family – redundancy or specialization? Physiol. Plant. 117: 155-63, (2003).
9. Joe Pokana and John Paul, Mine Site Rehabilitation, A Case Study – PNG’s WauNamie Mine Site, Paper presentation – 7th Geology, Exploration and Mining Conference held on 23–25th May, 2005, (2005).
10. Harvey, Julie K. Water Encyclopedia - Science Issues, Pollution Sources: Point and Non Point, http://www.waterencyclopedia.com/Point-Pollution-Sources-Point-and-Nonpoint.html, (2011).
11. Mineral Policy Institute, Overview of Mining in PNG, 2008-2012, http://www.mpi.org.au/png-overview.aspx, (2012).
12. Nancy Adams, Dawn Carroll, Kelly Madalinski, Steve Rock, Tom Wilson, Bruce Pivetz of ManTech, “Introduction to Phytoremediation”, United States Environmental Protection Agency, Office of Research and Development, http://nepis.epa.gov/EPAA/html/DLwait.htm?url=Adobe/PDF/30003T7G.PDF, (2000).
13. Pilon-Smits E. Phytoremediation, Annu. Rev. Plant. Biol. 56: 15-39. Available at arjournals.annualreviews.org, (2005).
14. Phytoremediation: A new hope for the environment, http://arabidopsis.info/students/dom/mainpage.html
15. Salt DE, Prince RC, Pickering IJ, Raskin I. Mechanisms of cadmium mobility and accumulation in Indian mustard. Plant Physiol.109: 1427-1433, (1995).
16. SALT, D.E. and KRAMER, U. Mechanisms of metal hyperaccumulation in plants. In: RASKIN, I. and ENSLEY, B.D., eds. Phytoremediation of toxic metals: using plants to clean-up the environment. John Wiley & Sons, Inc., New York, p. 231-246, (2000).
17. Schnoor, J.L., Licht, L.A., McCutcheon, S.C., Wolfe N.L. and Carreira, L. Phytoremediation of organic and nutrient contaminants. Environmental Science and Technology, 7, 318A-323A.68, (1995).

18. Stephen UW, Schmidke I, Stephan VW, Scholtz G. Thenicotianamine molecule is made-to-measure for complexation of metal micronutrients in plants. Biometals 9: 84-90, (1996).

19. Steve C. McCutcheon, Jerald L. Schnoor, Phytoremediation: transformation and control of contaminants, http://books.google.com/books?id=5zE-

20. Von Wiren N, Klair S, Bansal S, Briat JF, Khodr H, Shiori T, Leigh RA, Hider RC. Nicotianamine chelates both Fe(III) and Fe(II). Implications for metal transport in plants. Plant Physiol. 119: 1107-1114, (1999).

21. Water Quality Division, Vermont Surface Water Management Strategy, “Appendix C - Human Activities as a Source of Pollutants and Water Quality Problems”, http://www.anr.state vt.us/dec//waterq/wqd_mgtplan/swms_appC.htm, (2003).