Decision Making for Biosolids Management

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Abstract

All wastewater treatment processes produce solid waste in the form of “sludge” which, in its stabilized form, is termed “biosolids”. The term “biosolids management” broadly encompasses sludge stabilization and end-use or disposal of the biosolids. With growing population and higher wastewater treatment standards, the quantity of solid waste is increasing in many communities. Environmental, social and economic pressures are constraining the options available for sustainable biosolids management. Sludge stabilization technologies are developing at a rapid pace and biosolids handling methods are evolving to address these challenges but there is no “one-size fits all” solution. Communities are most often faced with a complex range of options to establish an optimum solution to address their specific issues and objectives. It is, therefore, important to arrive at an appropriate decision, satisfying environmental, social and economic requirements, under circumstances specific to the communities. This paper highlights the complexity of the decision process and hence the need to adopt a structured approach, and demonstrates the use of a decision software tool, Criterium® DecisionPlus® (CDP), to perform a Triple Bottom Line (TBL) assessment of options as part of the development of a biosolids management plan for a typical small/medium size wastewater treatment plant.

Keywords: *sludge stabilization, biosolids management, Criterium® DecisionPlus®, CDP, triple bottom line, TBL, 3BL*

1 Introduction

All wastewater treatment processes produce solid waste in the form of sludge. For a typical biological wastewater treatment system (assuming a fixed Solids Retention Time (SRT) within the typical range and consistent temperature and influent characteristics), sludge generation is proportional to BOD removal and, if applicable, also to nutrient removal. For a wastewater treatment system adopting chemical phosphorus removal, the amount of chemical sludge produced is proportional to the amount of phosphorus removed and the degree of phosphorus removal. With the increasingly stringent standards required for wastewater treatment and increasing population contributing to wastewater generation, the amount of sludge is also increasing. The typical range for sludge yield in an activated sludge system is from 0.4 to 0.8 kg VSS/kg BOD removed (McFarland, 2000). For a nitrification process, typical sludge yield is 0.15 kg VSS/kg TKN removed. An activated sludge treatment plant with a nitrogen removal process that receives a medium-strength average wastewater flow of 10,000 m^3/day produces approximately 2,300 kg/day of dry primary and secondary solids (equivalent to approximately 9.5 m^3/day of dewatered sludge at 20% dry solids).

The raw residual sludge from wastewater treatment contains both biological and chemical contaminants. The sludge needs to be stabilized to reduce pathogenic organisms, vector attraction potential, odours and putrescibility. The stabilized form of sludge is termed “biosolids”. The biosolids need to be further managed - either being disposed of or reused. The term “biosolids management” broadly encompasses sludge stabilization and end-use or disposal of the biosolids.

The increasing amount of sludge produced from wastewater treatment processes and the need for sustainable biosolids management has become a challenge to most communities. Sludge stabilization technologies are developing at a rapid pace and biosolids handling methods are evolving to address these challenges. However, environmental, social and economic pressures, many specific to individual communities, are constraining the options available for sustainable biosolids management. There is no “one-size fits all” biosolids management solution.

Communities are most often faced with a complex range of options to establish an optimum solution to address their specific issues and objectives. It is, therefore, important to arrive at an appropriate decision, satisfying environmental, social and economic requirements, under circumstances specific to any particular community. This paper highlights the complexity of the decision process and hence the need to adopt a structured approach. There are several tools available to help with the decision making process, from spreadsheets to specialized decision software. One of the available software is Criterium® DecisionPlus® (CDP) by InfoHarvest (2006). The CDP software can be used to help perform a Triple Bottom Line (TBL) assessment of options as part of the development of a biosolids management plan. An hypothetical case study for assessing sludge stabilization technology options for a small/medium size wastewater treatment plant is presented in this paper. The objective of this paper is not to promote any sludge stabilization technologies nor the CDP, but to demonstrate the varieties of biosolids management options and the application of a structured decision making tool to derive a biosolids management option from the multifarious options.

2 Biosolids Management Options

2.1 End-Use/Disposal

USEPA (1993) classifies biosolids based on pathogen level as Class A or Class B under the Code of Federal Regulations Title 40 Part 503 (40 CFR 503). Class A biosolids must contain no more than very low levels of pathogens: <1,000 MPN fecal coliforms per gram of total dry solids or <3 MPN *Salmonella sp*. bacteria per 4 gram of total dry solids. Class B biosolids have less stringent standards for treatment: $<2x10^6$ MPN fecal coliforms per gram of total dry solids. In Canada, the regulations and guidelines for use of biosolids are at the provincial/territorial level rather than the federal level. Some Canadian provinces are referring to 40 CFR 503 while others are developing their own.

The end-use/disposal route dictates the degree of treatment/management, and thus classification of biosolids, or vice versa. Broadly, there are three end-use/disposal routes available: land application, surface disposal and thermal destruction.

Land application refers to the application of biosolids to land to either condition the soil or to fertilize crops or other vegetation grown in the soil (USEPA, 2000). The biosolids can either be applied to land in bulk or packaged in bags or other containers for smaller scale land application. The potential end-users of biosolids include: agricultural land, golf courses, flower/plant nurseries, garden centers, sod farmers, landscapers, parks, homeowners, etc.

Surface disposal refers to the placement of biosolids on an area for final disposal. Some surface disposal sites may be used for beneficial purposes as well as for final disposal. Surface disposal sites include:

- Monofils - landfills where only biosolids are disposed
- Surface impoundments and lagoons - disposal sites where biosolids with a high water content are placed in an open, excavated area
- Waste piles - mounds of dewatered biosolids placed on the soil surface for final disposal
- Dedicated disposal sites - sites receive repeated applications of biosolids for the sole purpose of final disposal
- Dedicated beneficial use sites - surface disposal sites where biosolids are placed on the land at higher rates or with higher pollutant concentrations than are allowed when biosolids are land applied for farming or reclamation, e.g., willow coppice or hybrid poplars plantations.

Typically, land application requires that the biosolids meets Class A requirements, although Class B biosolids are acceptable at some sites. Class A biosolids can be land applied without any pathogen-related restriction at the site, and can be bagged and marketed to the public for application to lawns and gardens. Class B biosolids have more limited application, and more often disposed of at dedicated beneficial use sites.

Thermal destruction of biosolids is the combustion of biosolids at high temperatures in an enclosed device. The heat completely destroys the organic matter in the sludge cake and turns the cake into ash. The flue gas is treated before being released into the environment and the waste heat is recovered. Thermal destruction involves high capital and operating cost. The gases released from a thermal destruction process into the atmosphere are often perceived as being potentially hazardous and stringent standards/guidelines often apply. The residual ash may be classified as hazardous, depending on its metal concentrations. The disposal route of residual ash is uncertain and potentially expensive. Thermal destruction is not currently a popular option for biosolids management.

In establishing a viable biosolids management plan, it is important to get a clear understanding of the end-use/disposal routes that are available and are appropriate for any particular community. The assessment of end-use/disposal routes should be undertaken in advance or alongside the assessment of stabilization technologies. A biosolids product without a local end-use/disposal option is unlikely to be economically or environmentally sustainable, so stabilization technology options need to be assessed with this in mind.

2.2 Stabilization Technologies

The raw sludge produced from wastewater treatment processes needs to be stabilized, as appropriate, for its intended end-use/disposal route. There are many technology options available for sludge stabilization. Table 1 compiles a list of the main available sludge stabilization options. This list is not necessarily comprehensive: it may not include all available technologies, but is a reasonable list of the types of technologies available, as known to the authors' at the time of the writing of this paper. The purpose of the table is not to assess or promote any of the technologies but to demonstrate the multifarious options available for sludge stabilization.

Table 1 - Main Available Sludge Stabilization Technologies

Main Category	Sub-Category	Biosolids Classification
Aerobic Digestion	Conventional Aerobic Digestion	Class B
	High Purity Oxygen Aerobic Digestion	Class B
	Cryophilic Aerobic Digestion	Class B
	Aerobic/Anoxic Digestion	Class B
	Autothermal Thermophilic Aerobic Digestion (ATAD)	Class B
	Vertical Shaft Autothermal Thermophilic Aerobic Digestion (VERTAD™)	Class B
Aerobic Digestion with Pretreatment	Sonication Followed by Aerobic Digestion	Class B
Anaerobic Digestion	Conventional Mesophilic Anaerobic Digestion	Class B
	Conventional Thermophilic Anaerobic Digestion	Class A
	Anaerobic Baffled Reactor (ABR)	Min. Class B
	Columbus Biosolids Flow-Through Thermophilic Treatment (CBFT3)	Class A
	High-Rate Plug Flow BioTerminator 24/85	Min. Class B
	Temperature Phased Anaerobic Digestion (TPAnD)	Class A
	Two-Phase Acid Gas Anaerobic Digestion (2PAD)	Typically Class B
Anaerobic Digestion with Pre-treatment	Thermal Hydrolysis (CAMBI/Biothelyse) Followed by Anaerobic Digestion	Class A
	Sonication Followed by Anaerobic Digestion	Class A/B
	Electrical Pulsation Followed by Anaerobic Digestion (OpenCEL™)	Class A/B
	MicroSludge™	Class A/B
	CROWN®	Class A/B
	Dual Digestion	Class A
	Eco-Therm™	Class A
Anaerobic Digestion with Post-treatment	Anaerobic Digestion Followed by Ozonation	Class A
Chemical Treatment	Standard Alkaline Stabilization	Class A/B
	N-Viro™	Class A
	CleanB™ (patented chemical)	Class B
	VitAG (patented chemical with nutrient addition)	Class A
Alkaline Stabilization with Pasteurization	EnVessel Pasteurization™ (EVP)	Class A
Conventional Solidification		Typically Class A

Main Category	Sub-Category		Biosolids Classification
Composting	Windrow		Class A
	Aerated Static Pile (ASP)		Class A
	In-Vessel	Vertical Plug Flow System	Class A
		Horizontal Plug Flow System	
		Agitated Bed System	
		Static Pod	
	Vermicomposting		TBC
Thermal Drying	Standard Direct Drying		Class A
	Standard Indirect Drying		Class A
	Combination of Direct and Indirect Drying (e.g. INNODRY® 2E)		Class A
	Vacuum Thermal Drying (e.g. DryVac™)		Class A
Solar Drying			Class A
Disinfection	Ferrate Addition		Class A
	Irradiation	Electron-Irradiation	TBC
		gamma-Irradiation	TBC
	Neutralizer®		Class A
Incineration: Combustive Incineration	Fluidized Bed Incinerator		Class A
	Multiple Hearth Incinerator		Class A
	Electric Incinerator		Class A
	Rotary Kiln Incinerator		Class A
	Plasma Assisted Sludge Oxidation (PASO)		Class A
Incineration: Thermal Gasification	Conventional Gasification		Class A
	Plasma Gasification		Class A
Pyrolysis			Class A
Wet Oxidation (e.g. ZIMPRO® and LOPROX®)			Class A
Supercritical Water Oxidation (SCWO) (e.g., AquaCritox®)			Class A
Note: TBC = To Be Confirmed			

Among the technologies listed, some are more established, i.e., having a long and well documented record of performance and operational experience, than others. Other listed technologies are relatively new to the market (innovative) or are still in development (embryonic). These innovative or embryonic technologies may offer attractive benefits over more established ones, but they will usually involve a higher degree of risk until their performance and operation can be proven in a full scale operational situation. Therefore, municipalities need to be careful to ensure that the benefits and risks of all technologies are fully investigated in relation to their site specific circumstances. A structured analysis, considering all relevant factors, is needed to ensure that the selected approach is optimized for each individual set of circumstances.

Municipalities must ensure that a selected biosolids management solution is technically sound, operationally achievable and financially viable. Technologies should be robustly evaluated, taking into account both initial capital costs and ongoing operational benefits and burdens. History tells us that a lower initial investment has often led to an ongoing operational burden for future generations.

Biosolids is an increasingly emotive subject and, in addition to technical and economic criteria, consideration also needs to be given to social (public/community) acceptability and environmental impact and sustainability. Quantifying these social and environmental issues alongside economic factors is extremely difficult. A comprehensive TBL analysis is increasingly popular being used to help with this analysis.

3 Triple Bottom Line Analysis

A Triple Bottom Line (abbreviated as "TBL" or "3BL", and also known as "people, planet, profit") analysis is a method to evaluate the cost and benefits of alternatives across a spectrum of social, environmental and economic attributes. It was originally used to measure organizational success, but it is now widely used for measuring the value of a program, project or option.

A typical, simplified TBL analysis for a biosolids management program may include the sub-criteria under the three primary criteria as presented in Table 2.

Table 2 - Typical Decision Making Factors for a Biosolids Management Program

Social	Environmental	Economic
➢ Odour Potential ➢ Operability and Maintainability ➢ Visual Impacts ➢ Truck Traffic Volumes ➢ Noise Potential ➢ Public’s Perceptions	➢ Beneficial Reuse Potential ➢ Air Pollutants Emission ➢ Carbon Footprint	➢ Life-cycle cost (including initial capital, replacement capital, operation and maintenance costs)

Note that some sub-criteria may be common to more than one primary criterium and some sub-criteria may not fit neatly into any of the primary criteria. For simplicity sake, these sub-criteria are often forced into a more appropriate primary criterium. Also note that sub-criteria should not be repeated in order to avoid “double counting” or bias against any primary criterium.

To systematically analyze the cost-benefit of each available sludge stabilization option, a relative weighting must be assigned to each of the criteria and sub-criteria. This weighting will be specific to any municipality or community and must be developed on a case-by-case basis. Consultation and engagement with all relevant stakeholders within any community is strongly encouraged in this regard. There will not always be unanimous agreement on the weightings, but if a structured process is followed, some degree of consensus can usually be found. With weightings assigned, each stabilization option can then be scored or ranked against sub-criterium. The rating for each option would subsequently be quantified. As the sub-criteria and options get more complex, the analysis becomes challenging especially when sensitive analysis is required. A structured decision making tool, such as the CDP software, could then be used to help conduct the cost-benefit analysis systematically.

4 Criterium® DecisionPlus® Software

CDP helps users make complex decisions among options involving multiple criteria. It supports the two leading methodologies for multi-criteria analysis (Analytical Hierarchy Process (AHP) and Simple Multi-attribute Rating Technique (SMART)) and uncertainty analysis.

CDP calculates which option best meets the decision-maker's criteria, and how likely that alternative is to be truly the best choice, even in the face of uncertainty.

Figure 1 is the flow diagram showing the process that CDP supports.

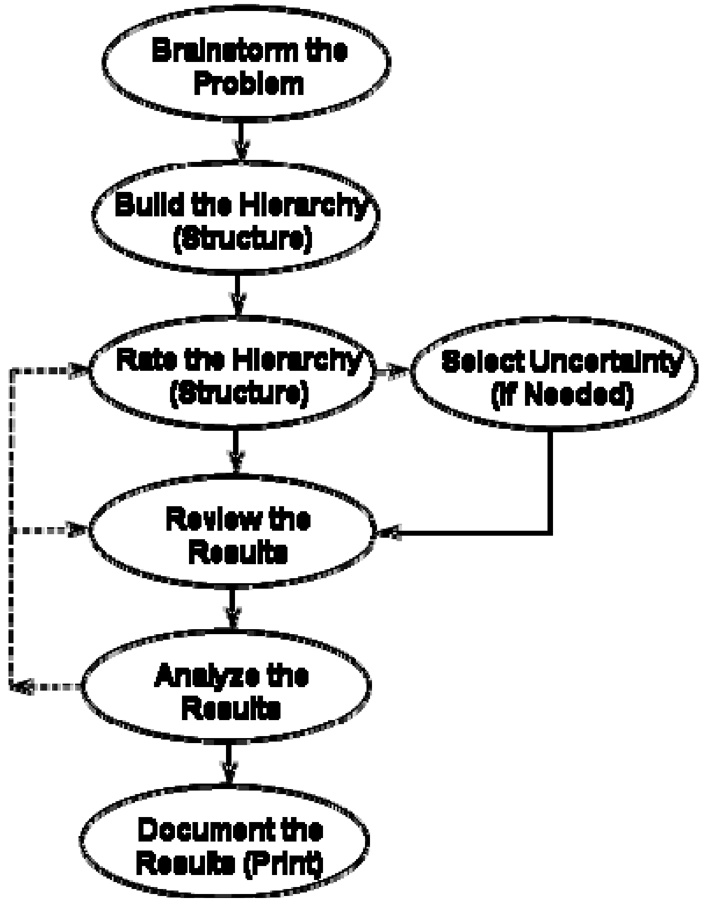

Figure 1 - CDP Flow Diagram

5 Hypothetical Case Study

To demonstrate the application of CDP software for the TBL analysis for choosing a sludge stabilization option as part of biosolids management, a hypothetical case study is developed. Note that the decision making of the end-use/disposal of biosolids would need a separate decision making exercise. This case study only demonstrates major features of CDP and is not intended to provide detailed guidance for using the software.

Considering a small/medium size wastewater treatment plant, the potential shortlisted sludge stabilization options are: aerobic digestion, anaerobic digestion, Autothermal Thermophilic Aerobic Digestion (ATAD), composting and thermal drying. The classification, types and potential markets of the biosolids resulted from the short-listed technologies are presented in Figure 2.

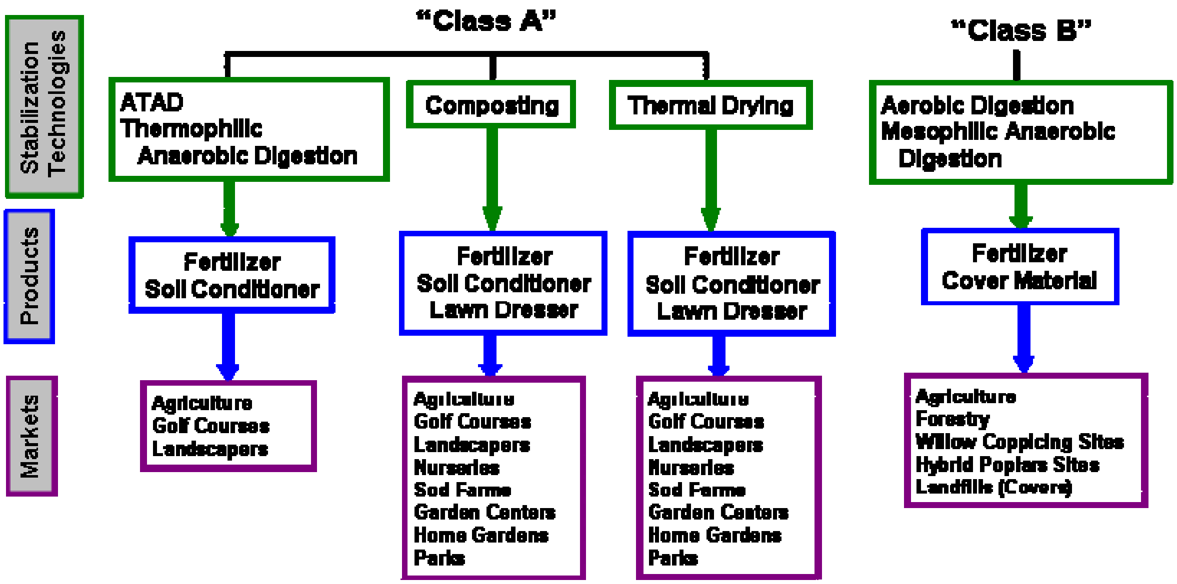

Figure 2 - Product(s) from Each Short-listed Process & Potential Markets for the Products

CDP allows users to select from two alternative techniques (AHP and SMART) and two hierarchy techniques (weights and trade-off). For this case study, AHP and the weight hierarchy technique were chosen.

Taking into account the TBL sub-criteria listed in Table 2, a hierarchy diagram as presented in Figure 3 could be developed with CDP. As shown on the figure, the first level (or first column) is the goal, i.e., to select a sludge stabilization option; the second level is the primary criteria; the third level is the sub-criteria; and the last column contains the stabilization options. The anaerobic digestion and composting options are sub-categorized into two sub-options, one with energy recovery/revenue return and the other without.

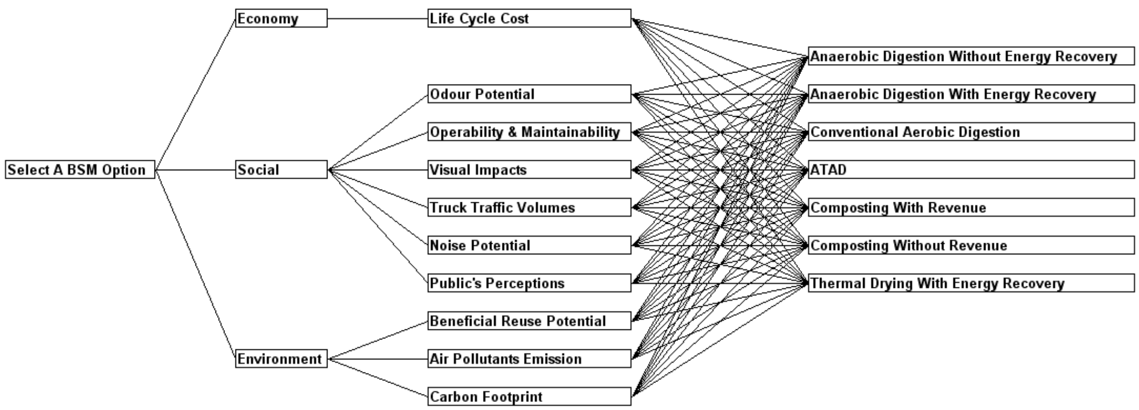

Figure 3 - Hierarchy Diagram

Each of the criteria and sub-criteria would be assigned with a weight. The weights are entered onto an AHP rating window, as shown in Figure 4. There are three rating methods - direct, full-pairwise and abbreviated pairwise. In this case study, direct method was chosen.

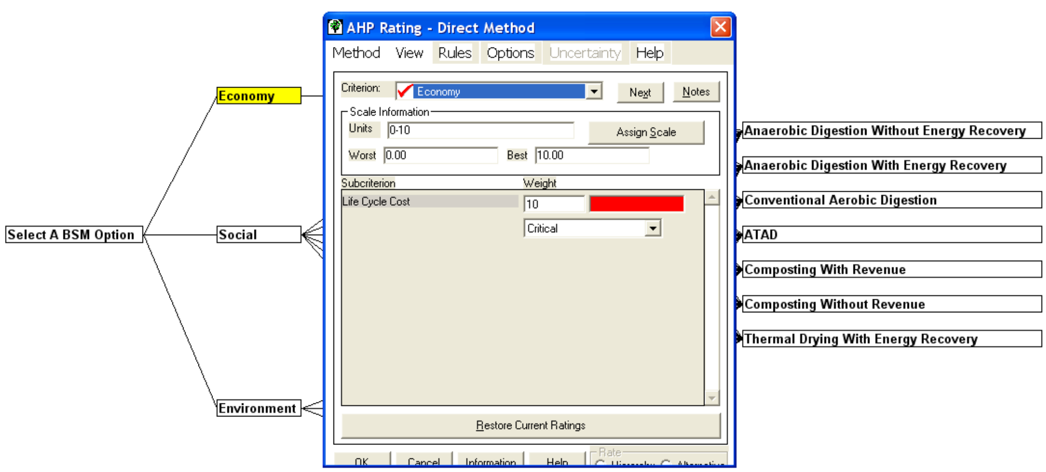

Figure 4 - Hierarchy Diagram with Floating Rating Window

After each criteria and sub-criteria had been rated, the scores of each alternative could be read from the Scores window, as shown in Figure 5.

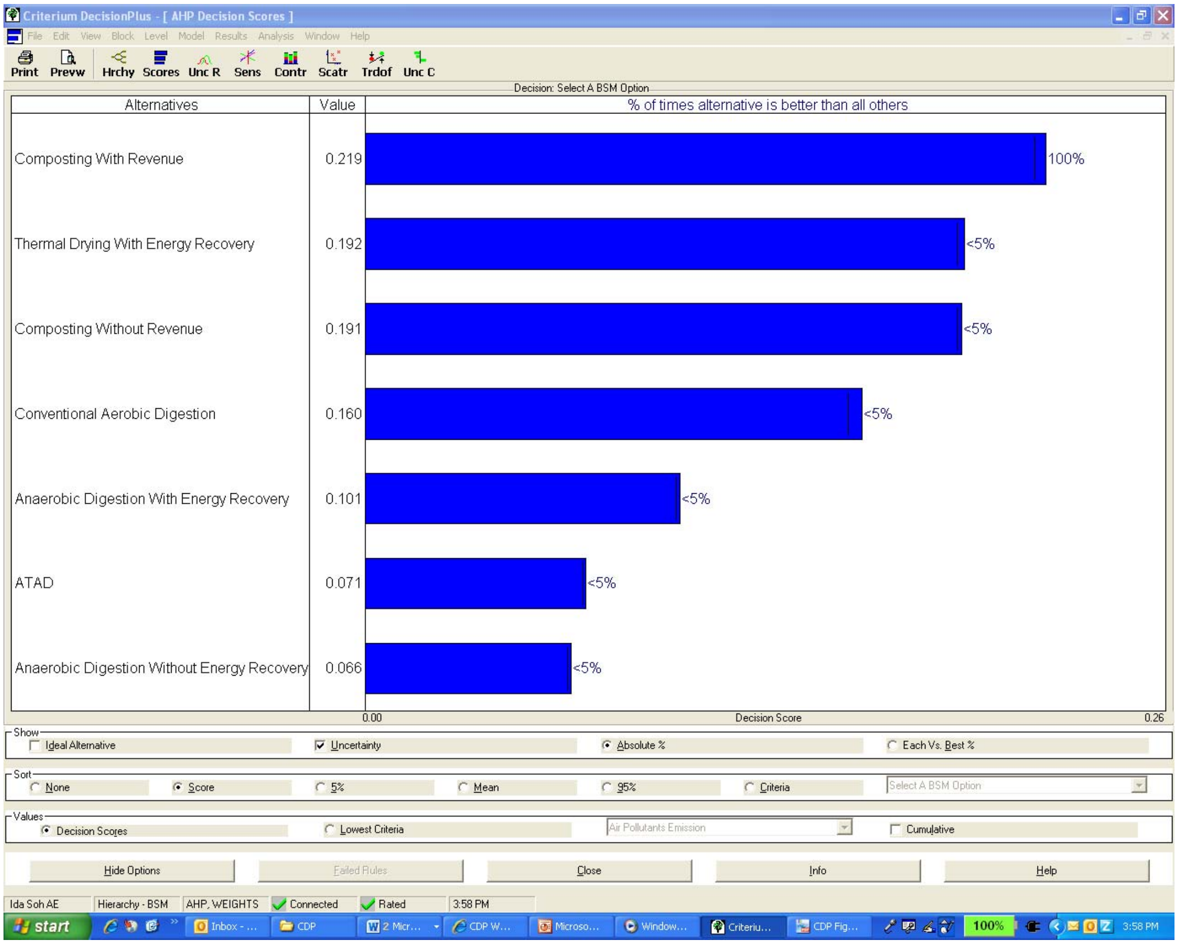

Figure 5 - Scores Window

CDP also allows the users to view the contribution of the criteria and subcriteria to the final score of each option, as shown in Figure 6. However, CDP can only show the score distribution up to 6 criteria or subcriteria.

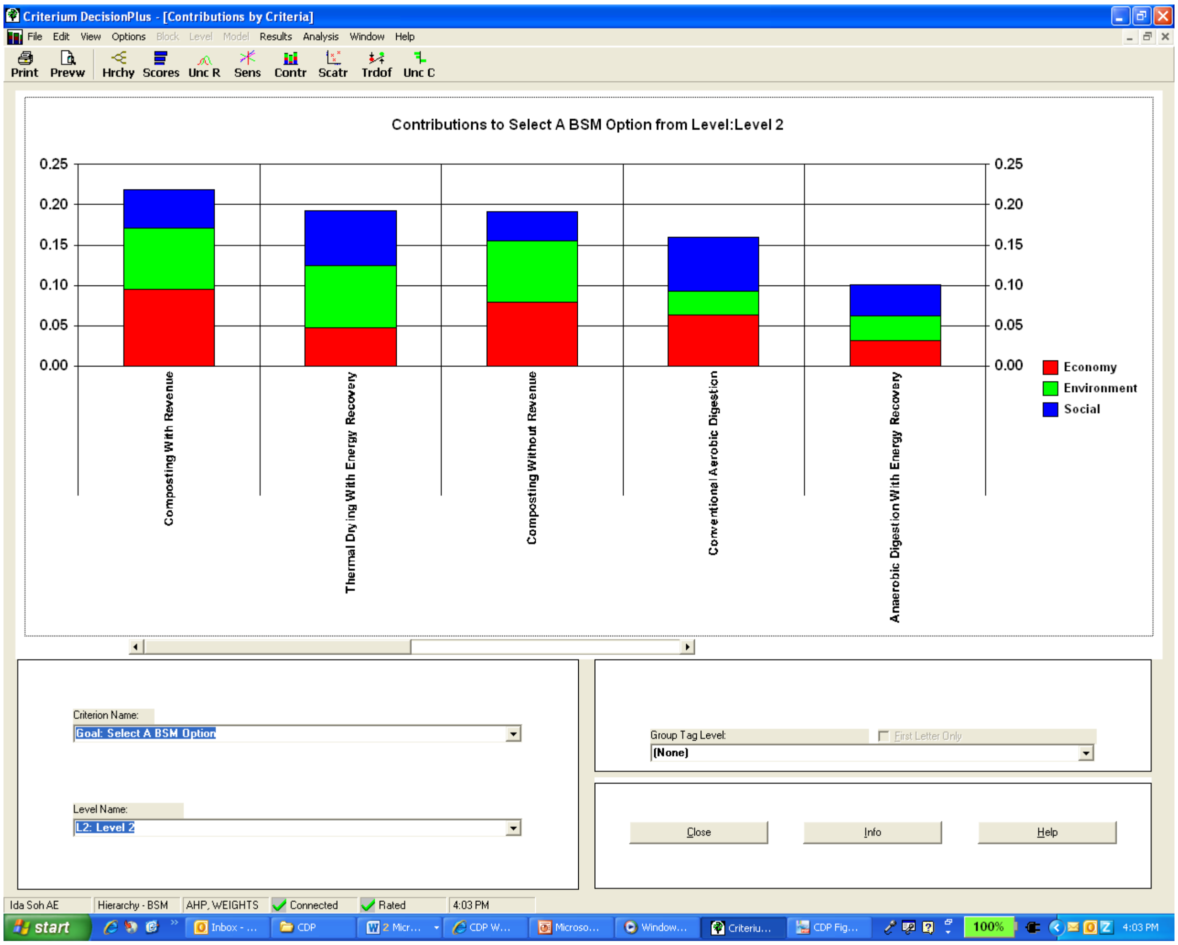

Figure 6 - Scores Distribution Window

Users could also conduct a sensitivity analysis, as shown in Figure 7.

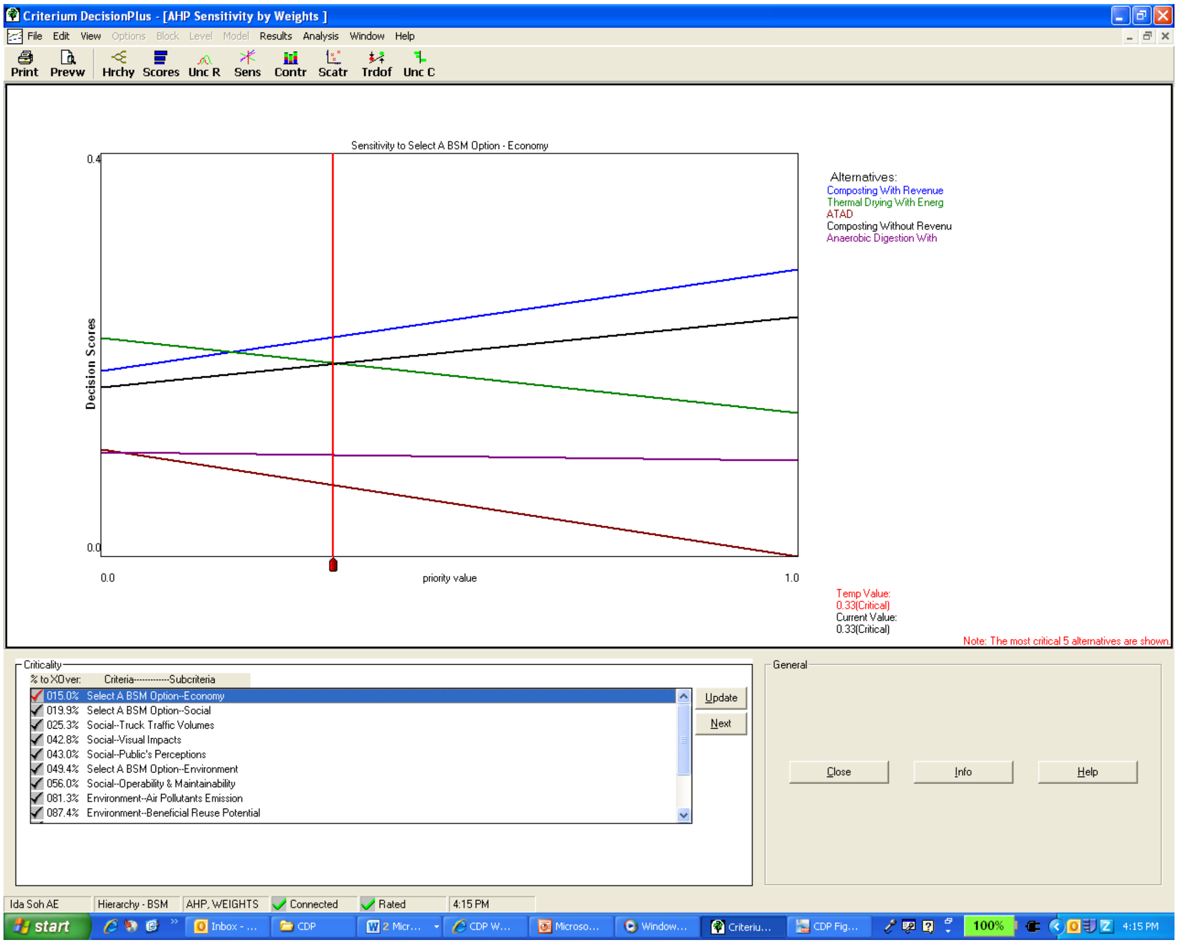

Figure 7 - Sensitivity Analysis Window

Based on the hypothetical weights provided and the results shown in Figures 5, 6 and 7, the “composting with revenue” option is the “winner”. The ranking of score contribution from the most to the least for this option is: economy > environmental > social. As the priority value of the life-cycle cost factor decreases (i.e., as the red cost factor line moves towards the left), thermal drying could be preferred over composting with revenue option.

6 Conclusions

The sustainable management of biosolids is becoming an increasingly significant issue for many communities. Biosolids quantities are increasing at the same time as financial, social and environmental pressures are constraining the options for sludge treatment and biosolids end-use/disposal. The technology industry is responding positively to this challenge, launching more and more new and innovative processes. However, the wider range of options is making the decision making process much more complex.

When faced with a wide range of biosolids management options, any particular community should:

- Understand that the available end-use/disposal routes are critical to establishing a viable management plan. An innovative and economic technology that produces a biosolids product with no long-term route for either end-use or disposal, is neither economically or environmentally sustainable.
- Assess if the available technologies meet available end-use/disposal routes. Technologies should be robustly evaluated, taking into account their life-cycle costs, including both initial capital costs and ongoing operational benefits and burdens.
- Drive the decision based on the needs and aspirations of the community since the optimum solution is usually site specific. Engineers, equipment vendors and suppliers can offer solutions and help facilitate the process but input from all stakeholders is needed to define the optimum option.

Making the right decisions now, in order to provide the optimum solution for the longer term, is presenting a significant challenge to many municipalities. The solution that looks the best today may not always look like a “good call” following years of troubled performance or expensive operation. While we do not have the benefit of hindsight at our disposal, a forward-looking, comprehensive, structured and robust approach to support decision making can always be adopted.

A structured decision making process using a TBL analysis can provide a good framework for the assessment of options. TBL will help ensure that comprehensive factors related to social, environment and economy be considered during the decision making process. The use of specialist decision software such as CDP can help structure the analysis and allow a better understanding of the results.

References

InfoHarvest, Inc (2006). Criterium® DecisionPlus® v. 3.0 User’s Guide.

McFarland, M.J. (2000). Biosolids Engineering. McGraw-Hill, USA.

USEPA (1993). Code of Federal Regulations, Title 40, Part 503: Standards for the Use and Disposal of Sewage Sludge (40 CFR 503).