

# **Evaluation of alternative discharging points from Valdivia Cellulose Plant by using Bayesian Belief Network Systems for Environmental Risk Management**

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**Evaluation of alternative discharge points from Valdivia  
Cellulose Plant by using Bayesian Belief Network System  
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**Anna Widén**

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**Title:** Utvärdering av alternativa utsläppspunkter från Valdivia pappersmassafabrik med hjälp av Bayesianska nätverk för miljöriskhantering.

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### **Sökord**

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### **Abstract**

In November 2004, Valdivia Cellulose Pulp Plant started operating in San Pedro de la Mariquina, 56 kilometers north-west of Valdivia in southern Chile. A few months later a decrease in the population of the Black Necked Swans (*Cygnus melancoryphus*) in the Carlos Anwandter Sanctuary, near the discharging point of the mill, was discovered. The aim of the thesis was to evaluate three alternative discharging points from Valdivia Cellulose Pulp Plant: Cruces River, San Pedro River and Mehuin near the Pacific Ocean. The evaluation was made with respect to ecological, social and economical values. A Bayesian Belief Network System (BN) was chosen as a method and the information was based on interviews with stakeholders, experts and the general public. The resulting BN indicated that the most suitable discharging point would be Mehuin near the Pacific Ocean.

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## Sammanfattning

I november 2004 startade Valdivia pappersmassafabrik sin produktion i San Pedro de la Mariquina, 56 km nordväst om Valdivia i södra Chile. Fem månader senare upptäcktes en plötslig minskning i populationen av de utrotningshotade svarthalsade svanarna (*Cygnus melancoryphus*) i våtmarksområdet El Santuario del Carlos Anwndter nära pappersmassafabrikens utsläppspunkt. Trots flera undersökningar i området kunde ingen entydig orsak till ekosystemreaktionen fastställas. Fabriken misstänktes vara skyldig till katastrofen och allmänhetens reaktion mot företaget var kraftig. Som ett åtgärdsförsök beslutade Chiles nationella miljökommission (CONAMA) att fabriken utsläppspunkt skulle flyttas.

Studiens syfte var att utveckla ett beslutsstöd och analysera tre alternativa utsläppspunkter från Valdivia pappersmassafabrik: Crucesfloden (den nuvarande utsläppspunkten), San Pedrofloden och Stilla havet bredvid byn Mehuin. Utvärderingen gjordes med avseende på ekologiska, ekonomiska och sociala faktorer. Slutligen utvärderades hur det använda beslutsstödet kan användas som ett redskap i riskhanteringsprocessen.

På grund av spretande och bristfälliga data och baserades studien huvudsakligen på intervjuer med intressenter, experter och allmänhet. Som metod för beslutsstödet användes Bayesianska nätverkmodeller eftersom de ger en övergripande bild av problemet och leder till fördjupad kunskap om relationer mellan viktiga faktorer. I detta fall var det holistiska perspektivet viktigt eftersom informationsmängden var låg och respondenterna oense i många frågor. I ett Bayesianskt nätverk kan beslutsalternativen länkas till respondenternas uppsatta mål genom intermediära faktorer. Därefter kan ett specifikt beslutsalternativ väljas i det interaktiva nätverket och de betingade sannolikheterna för att de uppsatta målen ska uppfyllas uppskattas. Därigenom kan olika beslutsalternativ jämföras och det som bäst uppfyller målen väljas.

Intressenter, experter och allmänhet intervjuades och baserat på respondenternas åsikter sattes målen för studien upp både på kort och på lång sikt; tre respektive 30 år. De kortsiktiga målen var att behålla arbetstillfällena och rekreation samt att minska den publika oron. På lång sikt ville respondenterna dessutom behålla god hälsa och de kulturella värdena i Mehuin. De kortsiktiga Bayesianska nätverken visade att alla utsläppspunkter hade sina för- och nackdelar beroende på vilket mål som observerades. Däremot indikerade modellen att Stilla havet i närheten av Mehuin var den bäst lämpade utsläppspunkten på lång sikt.

Om utsläppen faktiskt skulle komma att flyttas till Mehuin skulle troligtvis den totala nyttan för allmänheten maximeras, speciellt sett ur ett större geografiskt perspektiv. Däremot skulle flytten antagligen påverka innevånarna i Mehuin på ett negativt sätt. Pappersmassafabriken är av stor nationell betydelse och bidrar med arbetstillfällena, skatteintäkter och nationalekonomisk utveckling. Allmänheten ser fördelarna och vill delta i välfärden men är inte beredda att ta de konsekvenser som drabbar dem själva. Detta är en vanlig paradox som kallas NIMBY (Not In My backYard). I sådana situationer blir ofta minoritetsbefolkningar som är marginaliserade i samhället drabbade.

Slutsatsen av denna studie är att utsläppspunkten borde flyttas till Mehuin. Resultaten bör tolkas med försiktighet och det är av stor betydelse att ha en förståelse för hur nätverket är konstruerat. Analysen visar tydligt att den bästa lösningen kanske inte är den mest optimala om systemgränserna expanderar, då Tragedy of the Commons-syndromet blir gällande.

Vidare kan det Bayesianska nätverket med fördel användas som ett verktyg i riskhanteringsprocessen. Nätverket bör inte användas som en automatisk beslutsmaskin utan som ett verktyg för att belysa interaktioner mellan olika intressen, åtgärder och viktiga parametrar.

## Summary

In November 2004, Valdivia Cellulose Pulp Plant started operating in San Pedro de la Mariquina 56 kilometers north-west of Valdivia in southern Chile. A few months later a decrease in the population of the black necked swans (*Cygnus melancoryphus*) in the Carlos Anwandter Sanctuary, near the discharging point of the mill, was discovered. The public reaction was huge. Despite various studies, the actual reason for the environmental reaction could not be established. As a measure, Chile's National Environmental Commission (CONAMA) made the decision that the location of the effluents from the mill had to be changed.

The aim of the thesis was first of all to develop a decision support system (DSS) and evaluate three alternative discharging points: Cruces River (current discharging point), San Pedro River and Mehuin near the Pacific Ocean. The evaluation was performed with respect to ecological, social and economical values. Further, the method used in the DSS was evaluated as a tool in environmental risk management.

Due to scattered and incomplete data, stakeholder and expert interviews were decided to be the main source of information. Bayesian Belief Network System (BN) was chosen as DSS model, since it improves the overall knowledge of the problem. A holistic perspective was needed since the decision problem suffered from lack of data and there existed disagreements between stakeholders. When using a BN, the decision alternatives are added as management interventions and a specific alternative can be chosen by the decision maker in the interactive network. The conditional probabilities become updated throughout the whole network and the decision alternative's impact on the management objectives can be studied and compared.

The identified stakeholders and experts were interviewed and management objectives and other important parameters were stated, based on their opinions. The BNs were constructed based on these parameters and in two temporal scales; three and 30 years, respectively. The resulting BN showed that all discharging points had their benefits and drawbacks, depending on which management objective that was studied. The long term result on the other hand, indicated that Mehuin near the Pacific Ocean would be the most suitable discharging point.

If the discharging point were moved to Mehuin, the total benefit for the general public would probably be maximized, especially seen in a larger geographical perspective, but it would probably affect the people living there negatively. The mill is of great national importance and contributes with employment opportunities, taxes and national economic development, but the effluents are its drawback. The general public wants to take part of the public welfare and sees the benefits of the industry, but is not prepared to handle consequences that affect them. This is a common paradox referred to NIMBY (Not In My BackYard). In such cases, stakeholders not numerous and marginalized in the society tend to be affected. The solution of preferring the Mehuin site where the effluents will be discharged into the ocean can also be seen as a tragedy of the commons problem.

This report concludes that the BN indicates that the discharging point should be moved to Mehuin. The result should be carefully interpreted and it is important to have an understanding of the information that the network is constructed upon. The analysis clearly shows that the best solution may not be the best solution if the system boundaries were expanded, thus then the similarity with the tragedy of commons syndrome.

Further, the BN method can be used as a tool for risk management; from the risk analysis to communicating the final decision. The network should not be used as an automatic decision maker, but as a tool illuminating the interactions between certain interests, interventions and important parameters.



# Table of contents

<b>1. Introduction .....</b>	<b>1</b>
<b>1.1 Background.....</b>	<b>1</b>
<b>1.2 Task description .....</b>	<b>2</b>
<b>1.3 Target group .....</b>	<b>2</b>
<b>1.4 Disposition.....</b>	<b>2</b>
<b>1.5 Restrictions and limitations .....</b>	<b>2</b>
<b>1.6 Acknowledgement .....</b>	<b>3</b>
<b>2. Theory.....</b>	<b>5</b>
<b>2.1 Ecological risk and management.....</b>	<b>5</b>
<b>2.2 Decision support systems – Decision making under uncertainty .....</b>	<b>6</b>
<b>2.3 Stakeholder participation and academic expert opinions .....</b>	<b>7</b>
2.3.1 Risk perception .....	8
2.3.2 Collecting information .....	9
<b>2.4 Bayesian networks .....</b>	<b>9</b>
2.4.1 Theory behind the Bayesian Network models.....	10
2.4.2 Constructing a Bayesian Network.....	11
2.4.3 Sensitivity analysis in a Bayesian Network.....	12
<b>2.5 Summary – theory.....</b>	<b>12</b>
<b>3. Method .....</b>	<b>13</b>
<b>3.1 Problem area .....</b>	<b>13</b>
<b>3.2 Stakeholders.....</b>	<b>13</b>
<b>3.2 Decision Support Systems .....</b>	<b>14</b>
3.2.1 Interviews .....	15
3.2.2 Identifying nodes and node states.....	18
3.2.3 Bayesian network construction .....	19
3.2.4 Conditional probability .....	19
3.2.5 Sensitivity analysis .....	20
<b>3.3 Method – summary.....</b>	<b>20</b>
<b>4. Results .....</b>	<b>21</b>
<b>4.1 Interviews and identification of important parameters .....</b>	<b>21</b>
<b>4.2 Short term Bayesian networks’ node description .....</b>	<b>22</b>
4.2.1 Management Interventions .....	22
4.2.2 Intermediate factors .....	23
4.2.3 Management Objectives.....	35
<b>4.3 Long term Bayesian networks’ node description .....</b>	<b>40</b>
4.3.1 Management Interventions .....	40
4.3.2 Intermediate Factors.....	40
4.3.3 Management Objectives.....	47
<b>4.4 The Overall Result of Bayesian Network Modeling .....</b>	<b>51</b>

4.4.1 Short term result.....	51
4.4.2 Long term result.....	52
<b>4.5 Sensitivity analysis .....</b>	<b>55</b>
<b>5. Discussion .....</b>	<b>57</b>
<b>5.1 Discussion concerning short term results .....</b>	<b>57</b>
5.1.1 Employment opportunities .....	57
5.1.2 Public concern.....	57
5.1.3 Recreation .....	58
<b>5.2 Discussion concerning long term results .....</b>	<b>58</b>
5.2.1 Human health .....	58
5.2.2 Culture of Mehuin .....	59
5.2.3 Result short term .....	59
<b>5.3 General discussion concerning results.....</b>	<b>59</b>
<b>5.4 Bayesian network as a tool in environmental risk management .....</b>	<b>60</b>
5.4.1 Risk analysis .....	60
5.4.2 Risk evaluation .....	61
5.4.3 Risk reduction/control .....	61
<b>5.5 Biases .....</b>	<b>62</b>
<b>6. Conclusions .....</b>	<b>65</b>
<b>7. References .....</b>	<b>67</b>
Electronic sources.....	70
<b>Appendix 1: Background .....</b>	<b>71</b>
<b>Appendix 2: Discharging points .....</b>	<b>73</b>
Point nr 1: Cruces River.....	73
Point nr 2: San Pedro River .....	73
Point nr 3: Pacific Ocean – Mehuin.....	74
<b>Appendix 3: Stakeholder presentation .....</b>	<b>75</b>
3.1 CELCO-Arauco .....	75
3.2 Action for the Swans .....	75
3.3 San Pedro River Defense Committee .....	75
3.4 National Environmental Commission (CONAMA) .....	75
3.5 Universidad Austral de Chile (UACH).....	76
3.6 Mehuin Ocean Defense Committee .....	76
<b>Appendix 4: Results.....</b>	<b>77</b>
<b>Appendix 5 - Interview results .....</b>	<b>79</b>
5.1 CELCO-Arauco .....	79
5.2 Action for the Swans (APC).....	80
5.3 San Pedro River Defense Committee .....	82
5.4 CONAMA .....	82
5.5 Universidad Austral de Chile (UACH).....	83

5.6 Mehuin Ocean Defense Committee .....	85
<b>Appendix 6: Definitions .....</b>	<b>87</b>
6.1 Uncertainty.....	87
6.2 Probability .....	88
6.3 Risk .....	88
<b>Appendix 7: Short term Bayesian network for Cruces and San Pedro Rivers.....</b>	<b>90</b>
<b>Appendix 8: Short term Bayesian network for Mehuin .....</b>	<b>91</b>
<b>Appendix 9: Long term Bayesian network for Cruces and San Pedro Rivers.....</b>	<b>92</b>
<b>Appendix 10: Long term Bayesian network for Mehuin .....</b>	<b>93</b>

## Table of figures

Figure 1 North Valdivia and its surroundings. ....	1
Figure 2 A framework for environmental risk.....	5
Figure 3 The Risk management process stated by IEC (1995).....	5
Figure 4 Example of a Bayesian belief network system where node, node state and the conditional probability of the node states marked (Cain 2001). ....	10
Figure 5 The node A is a parent of the children B and C. ....	11
Figure 6 A schematic illustration of the temporal and spatial scales of the four Bayesian Networks. ....	21
Figure 7 The node Discharging point in the rivers' networks. ....	22
Figure 8 The node Discharging point in the sea networks .....	22
Figure 9 The node Process improvements,.....	23
Figure 10 The node Effluent improvements, which is similar in all four networks. ....	23
Figure 11 The node Pipe length, which is similar in both sea networks.....	23
Figure 12 The node concentration toxicant and its parents in the short term rivers' network. ....	24
Figure 13 The node concentration toxicant and its parents in the short term rivers' network. ....	24
Figure 14 The conditional probability table of the node Concentration toxicant in the rivers. ....	24
Figure 15 Calculation result of pollutant concentration in the rivers, with and without an increased production and with none, one or two effluent or process measures. ....	25
Figure 16 Conditional probability table concerning Concentration toxicant in the sea.....	25
Figure 17 The river functions and their parent in the short term rivers network. ....	26
Figure 18 The sea functions and their parent in the short term sea network. ....	27
Figure 19 The node Biodiversity and its parent, which is similar in all four networks. ....	28
Figure 20 The node Biodiversity's linearly distributed conditional probabilities, similar in all four networks. ....	28
Figure 21 The node Tourism and its parent in the short term sea network.....	28
Figure 22 The node Tourism and its parent in the short term rivers' network. ....	28
Figure 23 The nodes Perception Cleaner Effluents and Cleaner Effluents in the short term rivers' network. ....	31
Figure 24 The conditional probability table of the node Cleaner effluents. ....	32
Figure 25 The deterministic conditional probabilities for the Perception Cleaner Effluents node.....	33
Figure 26 The node Decicion CONAMA and its parents in the short term rivers' network. ....	33
Figure 27 The node Decicion CONAMA and its parents in the short term sea network.....	33
Figure 28 The conditional probabilities for the node Decision CONAMA in the short term rivers' network. ....	34
Figure 29 The node Fishermen and its parents, which is similar for both sea's networks. ....	34
Figure 30 The public concern node and it s parents in the short term rivers' network.....	35
Figure 31 The public concern node and it s parents in the short term sea network. ....	35
Figure 32 The conditional probability table of the node Public concern in the short term rivers' network. ....	36
Figure 34 The Recreation node and its parents in .....	37
Figure 33 The Recreation node and its parents in .....	37
Figure 35 The node Employment opportunities and its parents in the short term seas' network. ....	38
Figure 36 The node Employment opportunities and its parents in the short term rivers' network.....	38
Figure 37 The node Concentration toxicant and its parents in the long term rivers' network.....	40
Figure 38 The node Concentration toxicant and its parents in the long term sea network. ....	40

Evaluation of alternative discharging points from Valdivia Cellulose Plant by using Bayesian Belief Network System for environmental risk management

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Figure 39 The conditional probability table for the node Concentration toxicant in the long term sea network... 41  
Figure 40 The sea functions in the and their parent in the long term sea network. .... 42  
Figure 41 The river functions in the and their parent in the long term rivers’ network..... 42  
Figure 42 The Tourism node and its parents from the long term rivers’ network. .... 44  
Figure 43 The Tourism node and its parents from the long term sea network. .... 44  
Figure 44 The node public concern and its parents in the Rivers’ long term network. .... 47  
Figure 45 The node public concern and its parents in the Rivers’ long term network. .... 47  
Figure 46 The node Employment opportunities and its..... 48  
Figure 47 The node Employment opportunities and its parents in the long term rivers’ network..... 48  
Figure 49 The Culture of Mehuin and its parent in the ..... 49  
Figure 48 The deterministic conditional probabilities..... 49  
Figure 50 The health node and its parents in the long term sea network..... 49  
Figure 51 The health node and its parents in the long term rivers’ network. .... 49  
Figure 52 The conditional probabilities of the node Health in the long term rivers’ network..... 50  
Figure 53 The conditional probabilities of the node Health in the long term sea network. .... 50  
Figure 54 The relationship between different types of uncertainties (Lundin 1999)..... 87

## 1. Introduction

Chile is the most industrialized country of South America and the forestry is the third major business. The industrial development has contributed with social economic benefits but also with environmental drawbacks.

### 1.1 Background

In February 2004, Valdivia Cellulose Pulp Plant started operating in San Pedro de La Mariquina 56 kilometers north-west of Valdivia in southern Chile. The mill is owned by Cellulosa Arauco y Constitución S.A (CELCO-Arauco), produce 550 000 tons pulp per year for international exportation. Its effluents are lead to the nearby Cruces River, which on its way to the Pacific Ocean passed through a huge wetland, the Carlos Anwandter Sanctuary (see figure 1). The Sanctuary is famous for its rich birdlife and especially for the black-necked swan (*Cygnus melancoryphus*).

A few months after the mill started operating, the first signs of a substantial decrease in the population of the black-necked swan came (Marcotte 2006). The Chilean National Environmental Commission (CONAMA) contracted the Universidad Austral de Chile (UACH) to investigate the reason for the ecosystem collapse (Jaramillo *et al.* 2007). The study (UACH 2007) concluded that the death and emigration of the black-necked swans were due to a decrease in the prime producer and main source of food for the swans (*Egeria densa*), caused by the effluents from Valdivia Cellulose Pulp Plant. This was denied by CELCO-Arauco. Despite various ecological studies (see for example Jaramillo *et al.* 2007 and Marcotte 2006), no conclusion accepted by all interested parties have been presented and the actual compound causing contamination is still unknown.

CELCO-Arauco is still discharging in Cruces River and the environmental problems in the Carlos Anwandter Sanctuary are still very big. CONAMA have demanded CELCO-Arauco to change discharging point before the end of 2008. Several alternatives are considered but the two main locations are San Pedro (Calle Calle) River, upstream of Valdivia and in the Pacific Ocean near the fishermen settlement Mehuin, see figure 1. Cruces River and the alternative discharging points are described in Appendix 2.



Figure 1 North Valdivia and its surroundings.

The decrease in the swan population in the Sanctuary has led to a decreased faith in the company and there is hard to find acceptance for alternative discharging point among nongovernmental organizations (NGOs) and the general public. Missing transparency in the decisions and sometimes insufficient legislations have made people confused and there is lack of faith in both the company and politicians (oral comm. Claudia Sepúlveda APC 2007-10-20; oral comm. Teresa Castro 2007-10-22). The resistance against the mill is huge and the decision problem is related to far more dimensions than the ecological; such as social and political factors. The environmental problems have converted to social conflicts and the situation in the area is more or less locked. Many environmental and ethical studies have been performed but very few linking this two areas together. The situation is not a strict environmental, political or social problem, it is a mix of all areas and more studies taking all these factors into account are needed.

## ***1.2 Task description***

The citizens of Valdivia and the interested parties of Valdivia Cellulose Pulp Plant have been waiting several years for a decision to be made concerning the location of the discharging point of the factory.

The aim of the thesis is to build a Decision Support System and evaluate three alternative discharging points from the Valdivia Cellulose Pulp Plant. Since the environmental decision problem also has political and social dimensions, the case will be analyzed in ecological, social and economical terms and illustrated in a Bayesian Network based on stakeholder consultations. By varying the interventions stated in the Bayesian Network and optimize the benefit for all stakeholders, the optimal decision could theoretically be made. Further, the study aims to evaluate Bayesian Network as a tool in environmental risk management.

## ***1.3 Target group***

The master thesis is intended for decision makers and interested persons concerning the location of discharging points in Valdivia, Chile. The report will also be directed to persons interested in decision making and risk management and the application of Bayesian Networks in risk management.

## ***1.4 Disposition***

The report is based on an interview study. The first chapter consists of background, target group and restrictions and limitations. To build a basis for discussions, chapter two treats theory concerning environmental risk, stakeholder participation, the theory behind Bayesian networks and decision making. Chapter three describes the method used and in chapter four are the results presented. Chapter five discusses the results and biases and ends with the Bayesian Network's role in the risk management process.

## ***1.5 Restrictions and limitations***

Nine possible discharging points are of interest to the company CELCO-Arauco, but only three of them have been evaluated in this work. There may be other alternatives more suitable as discharging points than the ones studied, which should be considered when evaluating the results.

Only fluid effluents will be discussed in this report but also gaseous emissions and solid wastes are released from the factory (Arauco 2007).

In the study, the geographical area is limited to Valdivia and its surroundings but the CELCO-Arauco mill has both regional and national impacts. For example, the mill is of great national importance and the effluents may affect bigger areas than Valdivia. Also, Chile's national political situation has impact on the decisions and these factors are not illustrated in the model. Further, when considering the economical benefits and drawbacks, only the social-economic factors are included. The costs for implementing the different alternatives and interventions are not taken into account. With a decision comes both direct and indirect effects and only the direct effects are considered in this work. Further, no other threats to the ecosystems than the effluents are taken into account.

A limited number of stakeholders are interviewed and two meetings with each stakeholder are performed, even though Cain (2001) considers three interviews as the optimal number. The meetings lasted for one to two hours, aiming not to be too onerous for the stakeholders.

### ***1.6 Acknowledgement***

I would like to mention a number of people for their help and assistance during this master thesis. First of all I would like to thank my supervisors, Dr. Richardo Barra at Universidad de Concepción and Mats Svensson at LUCSUS, Lund University, who made it possible for me to go to Chile and who also have contributed with invaluable suggestions and advice. I would also like to thank Sophie Carler and Jonas Larsson for helping me with ideas and contacts.

Christian Björk has been of great support throughout the whole working process and has proofread the report together with Hanna Hållams, Johannes Näslund, Eva Sunnstedt and Marcus Abrahamsson. Finally I would like to thank all respondents participating in the study.





## 2. Theory

*Aiming to build a basis for further discussions, ecological risk and risk management, stakeholder participation, decision making and the Bayesian Network method will be discussed in this chapter.*

### 2.1 Ecological risk and management

Kaplan and Garrick (1981) define risk as a combination of probability and consequence. The definition (further discussed in Appendix 6.3) is useful when it comes to human health risks where the consequences often are easy to define; death, injuries, sickness, etc (Suter 1993). Environmental systems are related to a higher complexity and its consequences are harder to predict (McDaniels *et al.* 1995). Therefore, the consequence is often excluded from the definition. McDaniels *et al.* (1995) defines ecological risk as threats to the health and productivity of species and ecosystems, which will be used in this report. Further, the terms ecological risk and environmental risk will be used as the same concept.

To be able to make environmental risk related decisions, the risk has to be identified and evaluated (Hope 2006). There are several frameworks proposed concerning environmental risk assessment and management (Hope 2006, Suter 1993, Pollino *et al.* 2007).

The framework seen in figure 2 is presented by Suter (1993). He divides the risk management process in four parts: The hazard identification (1), where the endpoint is defined and the surrounding environmental and the sources of danger are identified. This is followed by a risk analysis (2) where an assessment of exposure and effect is performed and dose-response relationships are stated. The risk characterization part (3) is the summary of the risk analysis and the input to risk management (4). The risk related decisions and communication are made in the management node, aiming to reduce the risk stated in the risk analysis. (Suter 1993)

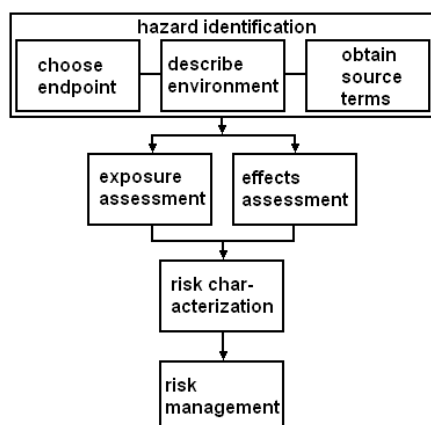


Figure 3 A framework for environmental risk assessment (Suter 1993).

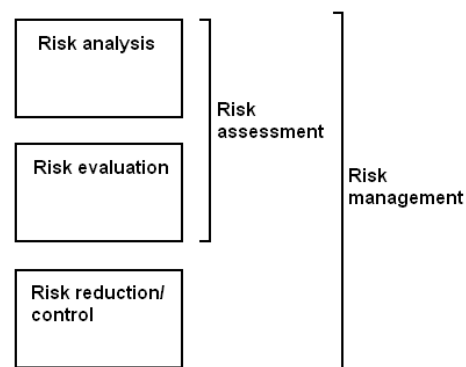


Figure 2 The Risk management process stated by IEC (1995).

The risk assessment is clearly separated from the risk management in Suter's (1993) model. The International Electrotechnical Commission (1995) has developed general guide-lines for risk management, where risk analysis, risk evaluation and risk reduction/control all are included in an overall risk management process, see figure 3.

In IEC's (1995) model, the risk analysis is based on Kaplan & Garrick's questions listed in Appendix 6.3. The concept of risk analysis is more general than in Suter's (1993) assessment approach and the methods for making risk analyses are wider. In the risk evaluation part, the decisions related to the tolerability of risk are concerned and the options of risk reducing options analyzed. Finally, risk reduction/control concerns decision making of risk reducing measures, followed by implementation and documentation of the decisions and results (IEC 1995).

Common for both approaches is the presence of the risk analysis. Independent of the risk management process chosen, the objectives of the study have to be clearly defined. This is especially of importance when it comes to environmental risk analysis because of the related complexity, mentioned above. Suter (1993) points out the difficulty in finding the adequate level of the analysis: Should the ecosystem functions such as biodiversity and production be protected or should the preservation be limited to species of commercial importance? Further, Suter (1993) jeopardizes the importance of choosing endpoints with importance to the general public, aiming to reach an acceptance while communicating the risks or the risk related decision. Instead of electing zoo plankton in the sea as endpoint for pollution, the fish eating the organism can be chosen, since decision makers or the general public has a greater interest in preserving the fish than zoo plankton.

It is important to have in mind that a higher hierarchical level of endpoint (for example fish instead of zoo plankton) increases the uncertainty in the assessment. Also, the complexity of the environmental system itself is related to high uncertainty. Therefore, it is important to find a suitable method for the environmental risk assessment. A method where significant changes on the endpoint are possible to detect and further illustrates the uncertainties in the result. (Suter 1993)

## **2.2 Decision support systems – Decision making under uncertainty**

Decisions concerning environmental issues have many different aspects (biological, social, ethical etc) (Matthies *et al.* 2005) and environmental systems are related to high uncertainty, as discussed in the section above. For a sustainable development it is important to take all these aspect into account (Matthies *et al.* 2005). In cases when a decision situation consists of different possible management options and several decision criterions have to be taken under consideration, Cain (2001) stresses that a Decision Support System (DSS) could be helpful in the decision process.

The concept of DSS is broad but can be defined as a computer based information system, which is flexible, interactive and developed for improved decision making concerning complex and strategic management problems (Matthies *et al.* 2005). A DSS helps the user structure the decision problem, improves the understanding for the management system and contributes with a more effective use of data and (Cain *et al.* 2003, Cain 2001).

At the same time, a DSS should be used with carefulness. There is a risk that the decision maker becomes over reliant of the DSS and disregards the possibility that the system is incomplete. In such cases, factors important for the decision could have been excluded from the model and therefore not a part in the decision process. Further, non-experts can sometimes have difficulties understanding the illustration of the system, which excludes them from the decision making process. Several methods for Decision Support System exist, for example Bayesian Networks, Influence Diagrams, Decision Trees, Mathematical modeling

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and Multiple Criterion Analysis (Cain 2001). The Bayesian Network will be further discussed in section 2.4.

All methods have benefits and drawbacks and when choosing method for DSS it is important to take objectives and conditions for the analysis into account. One essential factor to consider is the sources of data accessible for the analysis. According to Cain (2001) four types of information sources can be identified:

Type 1: Raw data collected from measurements.

Type 2: Raw data given from stakeholder, based on their experience.

Type 3: Results from modeling based on raw data collected from measurements.

Type 4: Expert opinions.

Generally, type 1 and 2 are more reliable than 3 and 4 and should be used if data is available (Cain 2001). Further, type 1 could be seen as more appropriate than type 2. On the other hand, if the investigation rather aims to evaluate how the interventions and risks are perceived, type 2 could be more useful (Cain 2001). Type 2 and 4 will be further discussed in the next section.

### ***2.3 Stakeholder participation and academic expert opinions***

The interest of integrating stakeholders and experts in the decision making process have increased in recent years (Matthies *et al.* 2005). A stakeholder is defined as anyone concerned of a subject; for example locals, employers, governmental or nongovernmental organizations (Cain 2001). There are several reasons for integrating stakeholders' opinions when building and validating a DSS model:

Industry, NGOs and the general public have an important role to play for stating objectives and identify socially relevant research questions (Welp *et al.* 2006). According to Kelly (1998), sustainable decisions cannot be made without consulting stakeholders. They have a "reality picture" of the situation and their participation can facilitate the DSS construction and smooth the progress of finding information that otherwise would have been hard to access (Welp *et al.* 2006).

Further, stakeholder consultations can link different science domains together (Welp *et al.* 2006). Scientists have a deep knowledge about their specific domain, but have sometimes difficulties understanding the importance of other sciences (Renn 1998). Because of the stakeholder's real life perspective, they can facilitate the connection between different areas of research. Also, in a field of disagreements, different stakeholder groups contribute with their view of the situation, which helps completing the picture of the problem (Cain 2001).

Including stakeholders in the whole decision making can facilitate the implementation of the outcome. Interested persons excluded from the decision making process could have difficulties accepting the decision or perceive the outcome as irrelevant (Bromley *et al.* 2005).

When stakeholders and experts are consulted in the DSS constructions, subjectivity is included in the model (Cain 2001). All people (both experts and the general public) are impacted of their background, culture and previous experiences (Teuber 1990), which is reflected in their statements. It is therefore important to understand subjectivity and people's risk perception (Slovic 2000). The factors affecting the public's risk perception and their

ability to adopt the concept of risk and probability as well as the ability for the experts to treat the same concepts, will be discussed in the following section.

### **2.3.1 Risk perception**

According to Kaplan and Garrick (1981), risk is dependent on the observer. This subjectivity is also referred to risk perception and can be seen as a combination of facts and valuations Riskkollegiet (1993). All individual's (both experts and the general public) perception of risk is dependent on several parameters such as age, family situation, ethnicity, experiences, attitude to safety and the person's possibility of influencing the situation. Also, the difference in risk perception between men and women has been examined. Women are generally more concerned and assess their own risk and safety knowledge as lower, compared to men. This could be the reason that more men than women each year are involved in fatalities. Further, there is a tendency that people with higher responsibilities are more concerned than others, for example a parent for its child (Enander 2005).

Risks can be divided into voluntary and involuntary risks, where the voluntary risk is defined as a risk taken by the person itself, for example extreme sports and car driving. Involuntary risks are imposed risks, as the installation of a nuclear plant or a paper mill on ones backyard. Generally, the voluntary risks are more accepted and are understood as less riskfull than the involuntary risk (Starr 1969). Further, the general public's demand of risk reducing measures is general higher if a problem is presented together with its consequence, rather as in probabilities Teuber (1990). The public tends to perceive risks with low probability and catastrophic consequences as more dangerous than risks with high probability and lower consequences (Slovic 1999). Also, people are generally more concerned about possible losses than appreciation of possible profits (Teuber 1990). This shows that people are inconsequent in their attitude towards risk and indicates that they can be seen as irrational when it comes to their risk perception.

Mattsson (2000) stresses that all people (the lay public, experts and decision makers) have bounded rationality concerning adopting and assessing information. Valuing risks is essential when it comes to decision making and according to Mattsson (2000), people general make decisions based on simple rules of thumb and concentrate on a low number of parameters, instead of thinking complex.

The difference between experts and the general public could be seen as the difference in knowledge concerning the origins and the backgrounds of the risks. As mentioned above, risk perception can be seen as a combination of facts and valuations. The expert is also impacted of these two factors but rely more on facts. If the experts do not have enough facts to rely on, they will act as the general public (Renn 1998).

The experts' judgments are generally seen as objective (Renn 1998), but the question whether there exists an objective risk or not have been discussed: Paté-Cornell (1996) argues that the use of experts' judgments could be affected by political benefits or certain interests. Also Cain (2001) states that the decision maker can be psychological biased towards certain information and for example value recent and more dramatic information higher than other.

In summary can be said that all individuals are impacted by previous experiences, which affect their risk perception. This is applied on both experts and the general public but the experts rely more on facts than people in general. Renn (1998) finally concludes that both

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experts and the general public should be taken into account when it comes to decision making, but both sides' weaknesses should be illustrated and taken into consideration.

### **2.3.2 Collecting information**

When have decided to include stakeholders and experts into the DSS, the information has to be gathered. The choice of method for collecting stakeholder opinions is dependent on the purpose of the study. The most common forms are questionnaires and interviews.

Questionnaires provide a bigger amount of participants and impact from the interviewer are avoided. Also standardized questions and their answers could be compiled more easily. Further, in a questionnaire all respondents are given the same questions, which are asked in the same order. This makes the results less biased. On the other hand, the possibility of ensuring that the respondents have understood the questions right or differences between personal answers, are lost when using questionnaires instead of interviews. In case when the interviewer aims to survey the problem from different angles or identify things important to the respondent, interviews are preferable, since a questionnaire in such cases could lead to missed information. Besides, interviews provide more exhaustive and detailed answers and misunderstandings could be avoided. Further, the questions could be modified and a greater openness between respondent and interviewer could be achieved (Körner & Wahlgren 2005).

Before an interview, structured but not standardized questions should be prepared. Standardized questions would ruin the idea of gathering information from stakeholders by interviews instead of a questionnaire. On the other hand, too unstructured questions can lead the interviewer to make an unaware selection of answers and just pay attention to certain parts (Körner & Wahlgren 2005).

To maintain the objectivity and avoid leading questions, the questions should as far as possible be asked in the same order in all interviews. This is of importance because one question may impact the interpretation of the following (Körner and Wahlgren 2005). Körner & Wahlgren (2005) further suggests that the questions should be formulated as equally as possible to all participants aiming to avoid the question being interpreted unequally.

## **2.4 Bayesian networks**

Different methods for DSS were listed and described in 2.2. When approaching a multi dimensional decision problem related to high uncertainty and lack of data, a Bayesian Network (BN) could be a suitable technique and will be described in this section.

The BN was first developed for treating uncertainty related to management system, aiming to make optimized decisions under uncertainty and have been successfully used for many years in medicine and in the field of artificial intelligence (Cain 2001, Bromley 2005). In recent years, the use of BN as a DSS-method has got more and more attention in environmental modeling, because of its transparent way of treating uncertainties, its holistic approach and allowance of integrating stakeholder and expert opinions (Henriksen *et al.* 2007, Wooff and Schneider 2006, Pollino *et al.* 2007)).

The method is based on Bayes theorem, which is useful for example when a case is suffering from lack of data or uncertain information (Cain *et al.* 2003). Further, the use of Bayesian statistics facilitate the use of both subjective and objective data as information source and the

model allows the combination of different kinds of parameters such as social and ecological ones (Cain 2001).

The geographical illustration improves the understanding of the system and gives the decision maker a holistic picture over the situation. The important parameters are clearly represented by nodes and the results are therefore relatively easy to communicate. Since all stakeholders' opinions are included in the network it facilitates the acceptance of the result among interested parties (Cain *et al.* 2003). Furthermore, the network treats uncertainty transparently by displaying current node state's standard deviation interval on the node box. Therefore, BN is a good tool for modeling environmental systems, which are related to high uncertainty.

On the other hand, the model cannot deal with systems with too high complexity (Cain *et al.* 2003). Further, if the information included in the network not is objective, the model cannot be used for making objective decisions (Cain 2001). The network should therefore be used carefully for decision making. Rather, the BN could be a help for the user structuring the problem, improve the understanding of the system and can work as a tool for optimizing the management support (Cain *et al.* 2003).

### 2.4.1 Theory behind the Bayesian Network models

The network consists of a number of variables linked to each other by arrows. The nodes represent parameters and the arrows illustrate the causal relationships between them. Each node can adopt different states (called node states), which are allotted a set of probabilities illustrating the likelihood of a node state if certain circumstances are given (Cain 2001). An example of a BN is found in figure 4, where nodes, node states and conditional probabilities are marked.

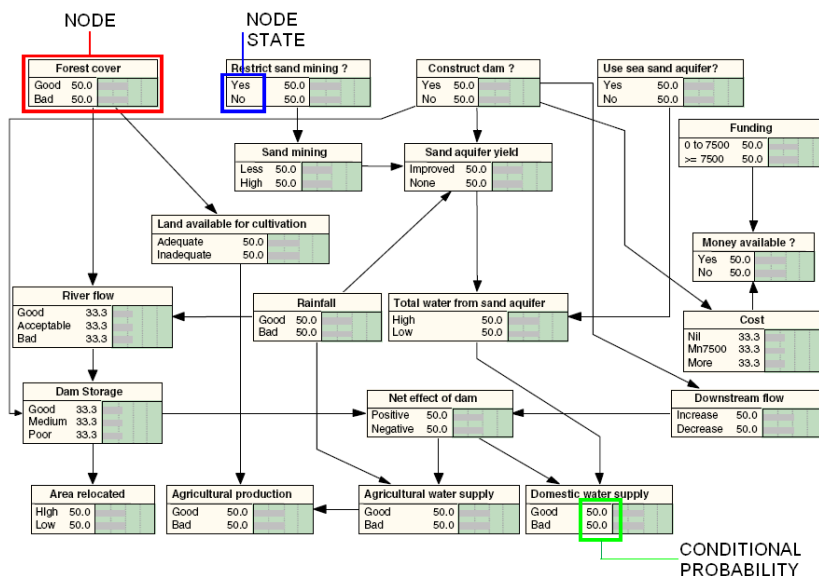


Figure 4 Example of a Bayesian belief network system where node, node state and the conditional probability of the node states marked (Cain 2001).

As mentioned above, the arcs between the nodes signify directly dependence between the nodes. In figure 5, node B and C are directly dependent on node A where A is the *parent* of

the *children* B and C. Further, the probability specification of node B and C is therefore directly dependent on the values of node A. The *conditional probabilities* of the children have to be specified by adding the probabilities for node B and C under the assumption that the value of the parent is known. (Wooff 2006) The conditional probabilities for B and C are denoted  $p(B|A)$  and  $p(C|A)$ . The conditional probabilities have to be allotted to all children of parents. By adding new information to the network, the probabilities for each node state will be updated throughout the whole network by using Bayes theorem in the software program.

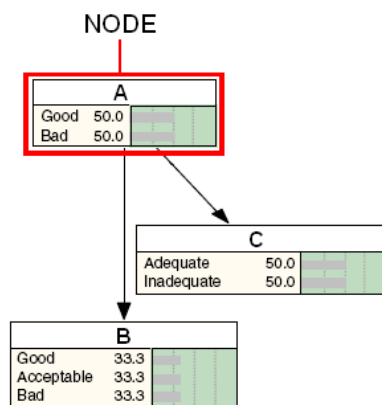


Figure 5 The node A is a parent of the children B and C.

### 2.4.2 Constructing a Bayesian Network

Methods for collecting information from stakeholders and experts were discussed in section 2.3.2. These consultations usually contribute with a lot of qualitative descriptions, which have to be turned into a quantitative model, aiming to obtain a fully functional BN. This will be discussed in this section.

By consulting stakeholders and experts, the objectives of the study, the possible interventions and parameters important for describing the situation can be stated. Thereafter, the variables should be organized in a network. To facilitate the BN construction process, it is preferable to divide the factors into categories before linking them together (Cain 2001). All the categories and their significances are listed in table 1.

Table 1 Description of categories used in the Bayesian network (Cain 2001).

Category	Description
<b>Management objective</b>	The desirable result of the management plan, including the factors which are wished to be improved or prevented from getting worse, for example "Employment opportunities".
<b>Interventions</b>	The measures, which are going to facilitate the Management Objectives to be achieved.
<b>Intermediate factors</b>	Factors which links Interventions and Management Objectives .
<b>Controlling factors</b>	Factors that affect the Management Objectives but cannot be controlled by implementing Interventions.

When all factors are categorized, they can be organized to a network. This can be done in a BN software for example in the software program Netica ([www.norsys.com](http://www.norsys.com)). The objective

of the mapping is to illustrate how changes in the management interventions affect the stated management objectives. Therefore, it is important to ensure that the interventions are not impacted by other nodes, since the decision maker is supposed to choose the states of the management interventions. Aiming to capture the important relationships in the decision problem it is essential to assure that the structure of the network is logic and make sense. This could be done by ensuring that the map only contains non-cyclic relations and that it only direct relations are represented with arrows (Nadkarni & Shenoy 2004).

Then, all scenarios in the conditional probability tables should be allotted a probability. The data could be of different sources as discussed in section 2.2. When all causal relationships are illustrated and the conditional probabilities filled in, a fully functional BN is achieved.

### 2.4.3 Sensitivity analysis in a Bayesian Network

The aim of a sensitivity analysis is to measure the sensitiveness of a parameter to another variable (Pollino *et al.* 2007). There are several ways of making sensitivity analysis in a BN and a quantitative method will be discussed here; sensitivity to findings. The most common measure of the parameter is entropy, but also mutual information is used. The entropy measure evaluates the uncertainty on a stochastic variable (A) characterized by a probability distribution,  $P(a)$  and the mutual information is a measure of the impact on a variable (A) from another (B). The entropy equation is seen in equation 1 and the mutual information in equation 2. If  $I(A, B) = 0$ , A and B are independent (Pollino *et al.* 2007).

$$H(A) = - \sum P(a) \log P(a) \quad (1)$$

$$I(A, B) = H(A) - H(A|B) \quad (2)$$

## 2.5 Summary - theory

Environmental systems are highly complex and driven by multiple goals and a DSS could facilitate risk related environmental decision making. There exist several methods for DSS and the use depends on the properties of the decision problem, for example type of available data. Stakeholder participation as model-input has been more popular in recent years and can contribute with inaccessible data and facilitate the implementation of the decision. When integrating stakeholders it is important to have in mind that all individuals are impacted by previous experiences, which affect their risk perception and further their opinions. The input in the model is not objective and cannot contribute with objective results.

When a decision problem concerns environmental systems suffering from lack of data, a BN could be a good method for modeling the DSS. When using a BN, the decision alternatives are added as management interventions and a specific alternative can be chosen by the decision maker in the interactive network. The conditional probabilities become updated throughout the whole network and the decision alternative's impact on the management objectives can be studied and compared.



### 3. Method

*The method used in the evaluation is described in this section. The chapter starts with a short presentation of the problem area followed by a description of the performance of the interviews. Thereafter, the use of the Bayesian Network is described.*

#### 3.1 Problem area

This case concerns the evaluation of three alternative discharging points from Valdivia Cellulose Pulp Plant; Cruces River, San Pedro River and Mehuin in the Pacific Ocean (see map, figure 1) in terms of ecological, social and economic benefits and drawbacks. The purpose of the study is to build a decision basis aiming to choose the most suitable discharging point.

According to Chilean law, the responsible company has to evaluate all possible discharging points and present the result in Environmental Impact Assessments for each point. Thereafter, the governmental and environmental organization CONAMA will decide the most suitable location for the effluents. Cruces River is the current discharging point and has its outlet in the Carlos Anwandter Sanctuary. The Sanctuary has been famous for its rich birdlife and has been the destination for many tourists. Five month after the mill started operating, among other species the Black Necked Swan started to die and emigrate and the population decreased from 5000 to 400 individuals (Artacho *et al.* 2007). The tourist companies in the region have lost many tourists and have moved their businesses to other watercourses (oral comm. Roberto Salinas 2007-10-22).

After the population crash of the black-necked swan, CONAMA turned to Universidad Austral de Chile (UACH), which performed an investigation in the wetland, aiming to conclude the reasons for the immigration of the birds (Jaramillo *et al.* 2007). Many nongovernmental organizations have been interested in the case, for example the popular movement Action for the Swans, which have worked hard for creating a public opinion against the mill (oral comm. Claudia Sepúlveda, APC 2007-10-19).

The first alternative is to keep on discharging into Cruces River (the null alternative). The second option is San Pedro River, which was the main destination for the tourist companies when they no longer could operate in Cruces River. San Pedro River goes directly to the sea and it should be mentioned that 20 % of Valdivia city take its drinking water from the river, downstream the proposed discharging point (oral comm. Enrique Suarez, CONAMA 2007-10-23).

The third alternative is to discharge into the sea near the fishermen settlement Mehuin. This location has since the beginning been CELCO-Arauco's most preferable location (oral comm. Pablo Baraño 2007-10-17). The fishermen in Mehuin have ever since the first plans protested violently, because of the risk of contamination and decrease in the fish population (oral comm. Eliab Viguera 2007-10-23).

#### 3.2 Stakeholders

The first step in solving the decision problem was to identify stakeholders and interested persons, based on the problem area described above. The problem is concentrated around

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CELCO-Arauco and the decision maker CONAMA, which are obvious stakeholders. Other interested persons are small scale fishermen and tourist companies, since they operate in the areas and their incomes are directly based on the watercourses. The general public is not directly economically concerned of any of the watercourses but well possibly affected both concerning health and wellbeing. Action for the Swans is supposed to represent the public opposition against the mill.

The environmental problems in Cruces River are very complex and the existing information is scattered and incomplete. UACH is seen as academic experts in the case, since they have worked in the problem area for many years, have performed several investigations and they are well informed about the problems concerning the discharging points. Six stakeholders were chosen and listed in table 2. They are further described in Appendix 3.

**Table 2 Identified stakeholders in the CELCO-Arauco case.**

<b>Stakeholder</b>	<b>Description</b>	<b>Representative</b>
<b>CELCO- Arauco</b>	The cellulose pulp plant	Pablo Baraño, Environmental engineer Miguel Osses, Environmental manager Angelo Romano, Economist
<b>Action for the Swans (APC)</b>	A public movement against the mill	Claudia Sepúlveda
<b>CONAMA</b>	The regional governmental environmental organization	Enrique Suarez
<b>Universidad Austral de Chile (UACH)</b>	The local university in Valdivia	Eduardo Jaramillo Pablo Villaroell
<b>San Pedro River Defense Committee</b>	The tourist companies' movement aiming to prevent contamination in San Pedro River	Eduardo Salinas X Salinas George Muller
<b>Mehuín Ocean Defense Committee</b>	A committee of fishermen operating along the coast in the lake district	Teresa Castro Eliab Viguera Gino Bavestrello

### **3.2 Decision Support Systems**

Many environmental studies have been performed in the Sanctuary and Cruces River (see for example Marcotte (2006) and Jaramillo *et al.* (2007)). Despite that, no generally accepted conclusion, explaining the ultimate courses concerning the case has been presented. This has caused confusion and disagreement between the stakeholder groups and many people are worried and concerned about the outcome of the decision. Also, incomplete information or lack of data concerning the alternative discharging points' adequateness makes the decision problem more complex. Environmental data from the sea does not exist, because of disagreements between the fishermen and CELCO-Arauco.

Decision making is included in the risk management process and before a decision can be made, the risk related to the case has to be identified and evaluated. At first sight, this problem is of environmental character but it is shown that both social and economic factors have to be taken under consideration when analyzing the risks. Further, no information concerning contaminating compound exists, which makes an environmental risk assessment

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unsuitable as risk management framework in this specific case. Therefore, the IEC (1995) model will be referred to in this report.

As pointed out earlier, a decision has to be made due to national and international pressure. Because of the situation's complexity, a DSS is thought to be a good help in the decision process. Aiming to get a holistic view of the problem and to be able to integrate expert opinions and the stakeholders' feelings and concerns into the decision process, a Bayesian Network was chosen as method for the DSS. BN provides the possibility to combine different types of data, it treats uncertainty and it illustrates the problem in a logic way which is easy to understand (Pollino *et al.* 2007). Besides, the lack of information has made the view among the interested persons highly spread and to illustrating the situation with a BN could help the decision makers get an overview of the situation.

To be able to follow the case over time and contribute with a sustainable decision base, the case was examined in both a long and a short term of time; three and thirty years respectively. For both time periods a local perspective was used.

### 3.2.1 Interviews

Because of lack of information and reliable data, data given directly from stakeholders and experts judgments were chosen as the main source of input to the model. Interviews were chosen as method for collecting information. Interviews are more flexible than questionnaires, since the interviewer can ensure that the respondents have interpreted the questions in the way the interviewer had intended.

Two interviews with each stakeholder group were performed. The aim was to consult the same person twice, but that was not always possible. The first interview had two purposes: First to get an overview of the situation in every stakeholder's point of view and second, to identify stakeholder objectives and how these objectives would be affected by the alternative discharging points. The structure of the BN was supposed to be constructed based on this information. The aim of the second interview was to validate the result of the first meeting and further allot probabilities to the nodes stated during the first consultation.

Before the interviews, structured but not standardized questions were prepared. The character of the interview questions was open and the respondents' brainstorming was an important ingredient. This was to ensure that no important information was left out and that the issues most important to the specific stakeholder were discussed. To maintain the objectivity and avoid leading questions, the questions were as far as possible asked in the same order in all interviews. To be able to analyze the answers afterwards, the interviews were recorded with a tape recorder. The general format of the conversations is presented in the following parts:

#### **First interview – preparation for Bayesian Network construction**

The meetings started with a short presentation of the project and the purpose of the study. The problems concerning the situation in the Sanctuary of Carlos Anwander and Cruces River were discussed. Thereafter, the three alternative discharging points were presented and the people possibly affected by the decision and the current status of the locations declared. As an introduction, the respondents were asked about their activities and their objectives of the company or organization they represented, how they wanted to achieve the objectives and if there were any menaces to them. Both long and short term answers were requested in all

questions. Further, questions concerning the discharging points and their possible effects on their activities were made. The stakeholders were requested to image and describe the best, worst and most probable scenario with and without the discharging point both in long and short term. In order to get an idea of their knowledgebase, some questions were asked about which toxicant they were most worried about and how they believed it would affect their activities. Finally, a discussion was held regarding the stakeholders' most preferable way to solve the situation. Because of different interests, knowledge and the way the stakeholder was interested in the case, the meeting focused on different things. The interviews will be discussed in detail later.

### **Second interview – preparation for allotting conditional probabilities**

To achieve a fully functional BN, each node had to be allotted a conditional probability. A second stakeholder interview was performed aiming to collect data for filling in the probability tables in the BN software. Another purpose of the second interview was to let the stakeholders validate the networks constructed after the first meeting. To facilitate the understanding for the network and also minimize the interview questions, a question form was prepared. Each node and its node states were noted and presented in a table, where the probabilities could be filled in by the stakeholders. The general structure of the second interview was as follows:

The question form contained the possible scenarios leading to the success state of a specific node. The original plan was to let the stakeholders fill in the probability directly, but it turned out to be too complex for some of the stakeholders. In some cases, such data collection was possible and was then performed. In the other cases, the respondent was requested to rank the scenarios after the probability to lead to the success state. The ranking was made by using terms as “very probable”, “probable”, “not probable” etc. This was repeated for all nodes, apart from the intervention nodes.

The aim was to follow this general structure, but that was not always possible. Also, some of the respondents of the first interview were not available for the second meeting and were therefore exchanged. Details concerning each interview are found in the following sections.

### **CELCO-Arauco**

**Interview 1: 2007-10-17 Pablo Baraño, Environmental engineer Miguel Osses, Environmental manager**

**Interview 2: 2007-11-19 Angelo Romano, Economist and CELCO-Arauco social expert**

At Valdivia Pulp Mill the meeting was held with two of the company's environmental engineers. The meeting started with a guided tour inside the mill, to the discharging point in Cruces River and finally to a location where a mesocosm study was held for evaluation of the effects of waste water on *Egeria densa*. After the study visit the interview was held and the company was asked to purpose other stakeholder groups. Thereafter, the interview followed the general structure presented earlier in this section.

The second interview was held at the CELCO-Arauco office in Valdivia with the “social expert” of the mill, since the environmental specialists had limited knowledge about the social questions. In other words, the reason for the exchange of respondent was to be able to better

capture the social and economic aspect of the problem. The interview followed the structure of the second interview presented above.

**Actions for the Swans**

**Interview 1: 2007-10-19 Claudia Sepúlveda**

**Interview 2: 2007-11-21 Claudia Sepúlveda**

A representative for APC was interviewed and asked to list other possible stakeholder groups. The interview followed the general structure both on the first and the second meeting.

**San Pedro River Defense Committee**

**Interview 1: 2007-10-22 Roberto Salidas**

**Interview 2: 2007-11-21 Jorge Muller**

San Pedro River Defense Committee was interviewed both as an organization and a company. Since they were mainly concerned by the rivers and lakes, the interview focused on those locations. Apart from that, the interview followed the general structure both on the first and the second meeting. Roberto Salidas was not available for the second meeting why Jorge Muller was interviewed instead.

**CONAMA**

**Interview 1: 2007-10-23**

**Enrique Suarez**

When interviewing CONAMA the general structure could not be followed since CONAMA not is personally concerned in the same way as the majority of the other stakeholders. The purpose was to get a holistic picture of how the different alternatives would affect future actions both from CELCO-Arauco and CONAMA.

CONAMA were asked to describe their work, give a brief of the situation. They were requested to state their objectives concerning the case and prioritize between the answers. Further, a discussion was held about the contamination, the status and the recovery possibilities of Cruces River. The contaminating compound was discussed and most important ecological parameters for a remained ecosystem were listed. Also, the question whether other threats to the ecosystems exist, a part from the mill was brought up.

Ecological, economical and social benefits and drawbacks and the ranking between the alternative points were discussed concerning all three locations. The worst, best and most probable case for each one were listed. Different possible technologies for better processes and effluent and their effect on the public opinion were discussed. Finally, a question concerning CONAMAs basis of decisions was posed; how the selection of discharging point would affect future decisions concerning CELCO-Arauco.

When CONAMA was contacted for a second interview they were prevented from coming and were not interested in further participation in the study.

**Universidad Austral de Chile (UACH)**

**Interview 1: 2007-10-23 Eduardo Jaramillo, Pablo Villaroell**

**Interview 2: 2007-11-20 and 21 Eduardo Jaramillo**

Representatives from Universidad Austral de Chile were used as academic experts and therefore, the interviews did not follow the general structure. As an introduction, the university was asked about the relationship between the university and the other stakeholders and the university's view of the situation. The interview focused on the ecological cause and effect relationships and sensitiveness. Also the importance of different ecological factors was brought up. The ecological differences between the discharging points and the best, worst and most probable case with and without effluent were discussed for each point. How the other stakeholders would be affected if the waste water was released in their area was brought up. Another important issue was the alternative process and effluent treatment, the effects of the measures and whether the technique is good enough for protecting the ecosystems.

During the second meeting the relationships stated in the first interview were discussed. Depending on their properties, some of the relationships were illustrated in dose-response graphs, some were filled in directly into the elicited probability table and others were ranked from high to low probability, as mentioned in the general structure.

**Mehuín Ocean Defense Committee**

**Interview 1: 2007-10-23 Teresa Castro and Eliab Viguera**

**Interview 2: 2007-11-21 Gino Bavestrello**

The meeting with the fishermen in Mehuín focused on the situation nearby the sea, and the problems in the other watercourses were left out. An important ingredient in this interview was to get at deeper understanding of the fishery and the fishermen's dependence of the catch and tourism. Further, the interview followed the general structure in both interview one and two.

### **3.2.2 Identifying nodes and node states**

After the first meeting the preparation for the BN construction begun. All important factors mentioned in the interviews were identified and listed in two groups; the ones who were of interest in a long term and a short term of time. Thereafter, they were sorted into the categories mentioned above; objectives, interventions, intermediate factors and controlling factors. After the first division, the lists contained over 40 factors each. Similar factors from different stakeholders were put together and parameters which either were too detailed or not directly affected by the discharging points were deleted.

The objectives were divided into two groups; "management objectives", and "stakeholder objectives", depending on the agreement with the overall objectives of the study. All of the stakeholder objectives, which did not agree with the management objectives, turned out to affect the management objectives and therefore became "intermediate factors".

When all nodes were identified and classified, the so called node states were defined. The node states are the different conditions a node could adopt; the water quality could for example be good, bad or intermediate. When allotting the node states it is important to ensure that the node states are chosen in a way that the BN becomes logic. If it is not logic, there will

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be problems filling out the conditional probabilities. After identifying the nodes and node states, the construction of the network could begin.

### 3.2.3 Bayesian network construction

The discharging points were divided into two groups; rivers and sea. Further, one short term network and one long term network was constructed for each group, as mentioned in section 3.2. Therefore, four Bayesian Networks was constructed to illustrate the case (see Appendix 7-10).

After the interviews, the objectives and important factors were identified and divided into the categories management objectives, intermediate factors, controlling factors and management interventions, as described in 2.3.2. Thereafter, the nodes were organized into a network in the software program.

### 3.2.4 Conditional probability

Aiming to turn the network into a fully functional BN, all scenarios were allotted a conditional probability in the conditional probability table. The probabilities were based on interview answers from the second interview. Probabilities concerning environment and ecology were answered only by UACH, since they had an expert function in this case. Some questions were answered by all stakeholder groups whereas other just concerned one single stakeholder, which is presented in the results.

Since the data collection was made through several interviews, the qualitative answers had to be interpreted to quantitative values. Four methods for allotting the conditional probabilities were used: nodes ranked in between nodes, nodes ranked in between scenarios, linear nodes, equation nodes and deterministic nodes. The general methods are described below and were used as far as possible, but were not applicable on all nodes. Exceptions are marked in the result section.

#### Ranking in between nodes – tradeoff values

When a parent node had more than two node states, two or more of its children nodes were ranked in relation to *each other* and the result was illustrated by allotting the children different tradeoff values. At the tradeoff value the probability for success was set to 50 %. Values higher and lower than the tradeoff value were set to a probability of 100 % and 0 % respectively, or the other way around depending on whether the relationship was positive or negative.

#### Ranking in between scenarios

Aiming to allot conditional probabilities to a node with two or more parents, the scenarios could be ranked in relation to each other. If the knowledge was low, the probabilities were dealt linearly. Otherwise, the probabilities for each scenario were described by the stakeholders, either with numbers or with words. If words were used, they had to be translated to numbers to fit into in the probability tables. For translation, see table 3.

**Table 3** The oral description interpreted into probabilities.

<b>Description</b>	<b>Estimated probability</b>
Certain (positive)	100
Very probable	90
Probable	70
Intermediate	50
Low probability	30
Not probable	10
Certain (negative)	0

### **Linear nodes**

If the relationship between two nodes is known as positive or negative but the equation cannot be estimated, the relationship can be linearly illustrated. If the relationship is positive, the probability for success state given success state is 1 and probability for a negative result given success state is 0. Thereafter, the probabilities are linearly distributed in between these values.

### **Equation nodes**

If a quantitative node depends on two or more quantitative nodes and the parents impact the child to different extents, it can be useful to describe the relationship with an equation.

### **Deterministic nodes**

If a node has one single parent and the probabilities for all scenarios are either 100 % or 0 %, the node is deterministic.

## **3.2.5 Sensitivity analysis**

If a parameter in the BN is sensitive to input, more effort on finding adequate in-data is needed. By making a sensitivity analysis, the most sensitive parameters could be found and help the network constructor to prioritize between nodes, concerning information seeking.

A network contains a large number of parameters and it should be too time consuming testing all nodes. Therefore, the concentration node in the short term river network was chosen to be analyzed, since it has a central role in the case. The analyze method was the built-in function “Sensitivity to findings” in the software, which uses mutual information to measure the nodes most dependent of the selected node (see 2.3.3).

## **3.3 Method – summary**

Since the decision problem had a broad character with few available data and disagreements between stakeholders and a holistic picture of the situation is needed, the BN was chosen as DSS method. The identified stakeholders were interviewed and a BN was constructed based on their opinions and UACH was used as ecological expert. The conditional probabilities were allotted by using four general methods for interpreting the qualitative interview results to quantitative values. The result is presented in the following section and begins with an account of the interview results followed by a description of all nodes in the networks.



## 4. Results

The result chapter starts with stating of important parameters, identified during stakeholder consultations. Thereafter, all nodes included in the network are described in short and long term respectively. Finally, the overall result of the networks is presented and the chapter is finalized with a sensitivity analysis.

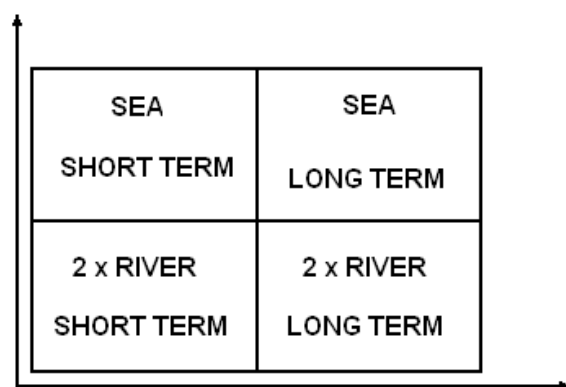
### 4.1 Interviews and identification of important parameters

The interviews were the basis of information and input in the BN. A review of the interviews is found in Appendix 5. Based on the stakeholder dialogues, the objectives of the study were stated and are listed in table 4. Further, all parameters affecting the management objectives and impacted by the discharging points were identified, also based on the stakeholder consultation. All parameters are listed in table 25 and 26 in Appendix 4 and were the basis for the BNs, which were constructed by illustrating the causal relationship between the factors and finally by allotting conditional probabilities to the network nodes.

**Table 4 Short and long term management objectives based on stakeholder consultations.**

Short term management objectives	Long term management objectives
Employment opportunities	Employment opportunities
Public concern	Public concern
Recreation	Recreation
	Culture of Mehuin
	Health

Three watercourses (two rivers and the sea) and two time levels (3 and 30 years) were illustrated. The rivers are geographically close and have impact on more or less the same people, why the rivers were illustrated in the same networks. Therefore, four BN were constructed as illustrated in the schematic figure below (figure 6). The complete networks are found in Appendix 7-10 and illustrate how the alternative discharging points and interventions affect the management objectives.



**Figure 6 A schematic illustration of the temporal and spatial scales of the four Bayesian Networks.**

## 4.2 Short term Bayesian networks' node description

In this section follows a review of all nodes in the networks, one by one. The chapter is divided into three parts; Interventions, Intermediate factors and Management Objectives.

### 4.2.1 Management Interventions

A management intervention is a factor which could be added to a system aiming to obtain the management objectives. When an intervention's node state is selected in the BN, its probable impact on the management objectives can be observed. The management interventions are not allotted a conditional probability because the node states are supposed to be selected by the manager.

The most obvious and important intervention is the discharging points, but a number of process and effluent measures have been discussed from several instances. Many organizations want CELCO to change its process from elementary chlorine free (ECF) to a total chlorine free process (TCF) (oral comm. Claudia Sepúlveda, APC 2007-10-19). Also, the company is currently investigating the environmental benefits of using a membrane technique instead of the tertiary waste water treatment. Further, a Brazilian company examines how an artificial wetland could be used for biological treatment of the effluents before discharging them into the watercourse. A third intervention is to increase the length of the pipe from letting the effluents reach the sea on the shoreline to discharge it a couple of kilometers out in the ocean, which is thought to decrease the risk of contamination (oral comm. Enrique Suarez 2007-20-23). The interventions treated in this report are discussed below.

#### 4.2.1.1 Discharging point

The nodes in figure 7 and 8 illustrate the discharging points with the node states "Cruces River", "San Pedro River", in the rivers' networks and "Yes" and "No" in the sea's networks. By choosing node states, the alternative discharging points' impact on the management objectives illustrated in the management objective nodes. The node states "Yes" and "No" have been chosen aiming to compare the effects with and without discharge.

Discharging point	
Cruces River	50.0
San Pedro River	50.0
1 ± 0	

Figure 7 The node Discharging point in the rivers' networks.

Discharge	
Yes	100
No	0

Figure 8 The node Discharging point in the sea networks

#### 4.2.1.2 Process improvement

In the node "Process improvements" (see figure 9), the option to choose process improvements or not can be considered. Changing from ECF to TCF was one of the stakeholders' propositions for improving the effluents and illustrated by this node. The node states are "Yes" and "No".

Process improvements		
Yes	50.0	
No	50.0	

Figure 9 The node Process improvements, which is similar in all four networks.

#### 4.2.1.3 Effluent improvement

The node “Effluent improvement” is illustrated in figure 10 can be changed to add measures for treating the effluent itself. This is made by exchanging the third waste water treatment to the membrane technique and letting the waste water pass through an artificial wetland before entering the ecosystem. The node states are “Yes” and “No”.

Effluent improvement		
Yes	50.0	
No	50.0	

Figure 10 The node Effluent improvements, which is similar in all four networks.

#### 4.2.1.4 Pipe length

Two types of pipe lengths have been discussed. The first alternative was to build a very short pipe, which releases the effluents directly within the shoreline and the other is to build a pipe of two to four kilometers. Therefore, the node states are “Short” and “Long”, see figure 11.

Pipe_length		
Short	50.0	
Long	50.0	

Figure 11 The node Pipe length, which is similar in both sea networks.

### 4. 2.2 Intermediate factors

An intermediate factor is the parameters which link the intervention nodes to the management objectives. The intermediate factors discussed by the stakeholders are presented below.

#### 4.2.2.1 Concentration toxicant

As seen in figure 12 and 13, the concentration toxicant is dependent on the water flow in the rivers and amount of water in the sea, the quality of the effluents, the production rate of CELCO-Arauco and the length of the pipe. The probabilities of the different scenarios are estimated by expert opinions from Universidad Austral de Chile (UACH). The respondents from the university have a higher educational level regarding these types of questions, why their answers are supposed to be more reliable than the information from the other stakeholders.

Evaluation of alternative discharging points from Valdivia Cellulose Plant by using Bayesian Belief Network System for environmental risk management

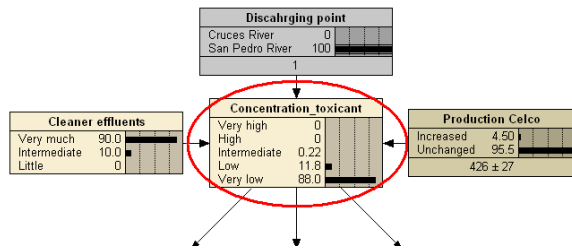


Figure 12 The node concentration toxicant and its parents in the short term rivers' network.

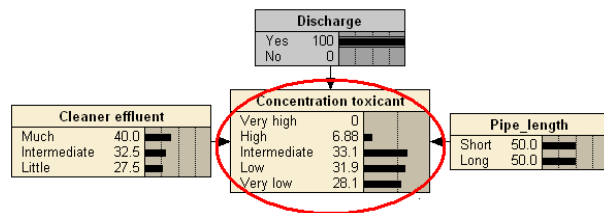


Figure 13 The node concentration toxicant and its parents in the short term rivers' network.

Cruces and San Pedro Rivers

The concentration of the toxic compound is child of the nodes “Discharging point”, “Cleaner effluents” and “Production CELCO”. According to UACH, the factor having the greatest impact on the concentration of the pollutant was the discharging point, closely followed by if the effluent interventions were carried out or not. The least important factor was the production rate. Since this node has five node states the allotting of conditional probabilities did not follow the general method presented in 3.5. All scenarios were rated by Eduardo Jaramillo, from the best to the worst case. The best case got 100 % probability for the success state (very low) and the worst case 100 % probability for the worst state (very high). Since the production rate was supposed to have minor impact, all scenarios with reduced production was allotted probabilities of 100 % for the probable concentration, equally distributed within the same discharging point. Thereafter, the scenarios with full production had its probability dislocated to higher concentrations with 50%-units (see figure 14).

Node: **Concentration\_toxicant** Apply Okay

Chance % Probability Reset Close

Disahrnging point	Cleaner effluents	Production Celco	Very high	High	Intermediate	Low	Very low
Cruces River	Very much	Increased	0.000	0.000	50.000	50.000	0.000
Cruces River	Very much	Unchanged	0.000	0.000	0.000	100.00	0.000
Cruces River	Intermediate	Increased	0.000	50.000	50.000	0.000	0.000
Cruces River	Intermediate	Unchanged	0.000	0.000	100.00	0.000	0.000
Cruces River	Little	Increased	100.00	0.000	0.000	0.000	0.000
Cruces River	Little	Unchanged	50.000	50.000	0.000	0.000	0.000
San Pedro River	Very much	Increased	0.000	0.000	0.000	50.000	50.000
San Pedro River	Very much	Unchanged	0.000	0.000	0.000	0.000	100.00
San Pedro River	Intermediate	Increased	0.000	0.000	50.000	50.000	0.000
San Pedro River	Intermediate	Unchanged	0.000	0.000	0.000	100.00	0.000
San Pedro River	Little	Increased	50.000	50.000	0.000	0.000	0.000
San Pedro River	Little	Unchanged	0.000	100.00	0.000	0.000	0.000

Figure 14 The conditional probability table of the node Concentration toxicant in the rivers.

To validate the information from the stakeholders regarding the concentration pollutants in the watercourses a simple calculation was performed where a fictive effluent concentration of 1 µg/l was divided by the water flow in the rivers. Further, calculations were made for a 20 % increase in the production and how the concentration would change with the effluent and process measures by reducing 25 % and 75 % of the pollutant concentration. The calculations supported the stakeholders' estimations, but the result of an increased production had a

greater effect in the calculations than in the estimations. See figure 15. The estimations made by the stakeholders were used as input in the conditional probability table.

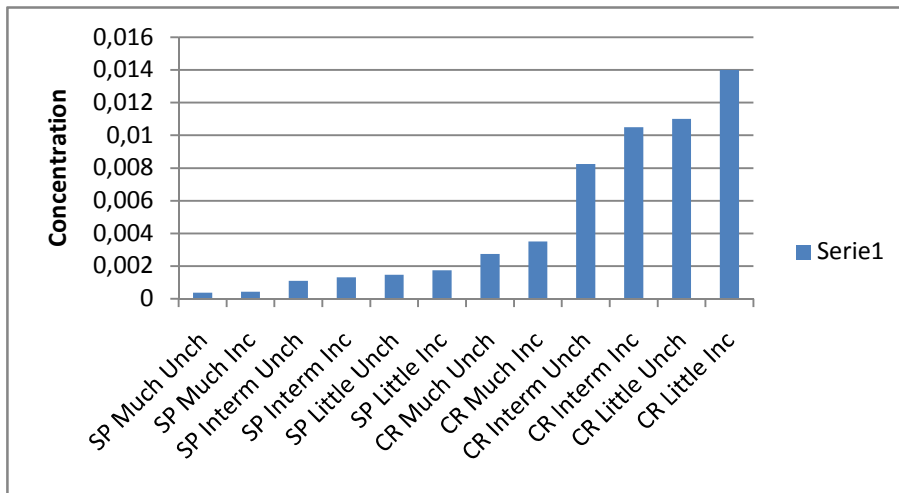


Figure 15 Calculation result of pollutant concentration in the rivers, with and without an increased production and with none, one or two effluent or process measures.

Mehuin

If the discharging point is moved to the sea, UACH does not believe that an increase in the production would affect the concentration in a short perspective, because of the high dilution. The concentration toxicant-node in the sea network, has another parent; the pipe length. UACH stresses that this parameter is the most important regarding the concentration of pollutants near the shore, where tourists and fishermen are located. The scenarios were ranked by UACH and the conditional probabilities were set based on the best case, which was allotted the probability 100 % for success state. The conditional probabilities were allotted linearly and the result is shown in figure 16.

Node: **Concentration\_toxicant** Apply Okay

Chance % Probability Reset Close

Pipe_length	Discharge	Cleaner efflu...	Very high	High	Intermediate	Low	Very low
Short	Yes	Much	0.000	0.000	50.000	50.000	0.000
Short	Yes	Intermediate	0.000	0.000	100.00	0.000	0.000
Short	Yes	Little	0.000	50.000	50.000	0.000	0.000
Short	No	Much	0.000	0.000	0.000	0.000	100.00
Short	No	Intermediate	0.000	0.000	0.000	0.000	100.00
Short	No	Little	0.000	0.000	0.000	0.000	100.00
Long	Yes	Much	0.000	0.000	0.000	0.000	100.00
Long	Yes	Intermediate	0.000	0.000	0.000	50.000	50.000
Long	Yes	Little	0.000	0.000	0.000	100.00	0.000
Long	No	Much	0.000	0.000	0.000	0.000	100.00
Long	No	Intermediate	0.000	0.000	0.000	0.000	100.00
Long	No	Little	0.000	0.000	0.000	0.000	100.00

Figure 16 Conditional probability table concerning Concentration toxicant in the sea.

#### 4.2.2.2 River functions: Fishing, excursions and water sports

According to all stakeholders, the tourists visit the rivers and the lake for different reasons. When Cruces River was a functioning ecosystem, the main attraction was watching birds by boat. Rafting and kayaking are the biggest reasons for tourists visiting San Pedro River.

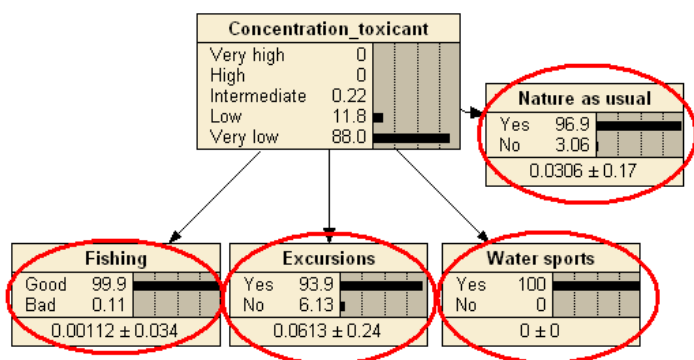


Figure 17 The river functions and their parent in the short term rivers network.

All activities can be seen as ecosystem functions, with different sensitivity to the concentration of the pollutant (see figure 17). According to the tourist company, rafting is more or less only dependent on flowing water. If the surrounding environment is not visibly affected, the tourists will come visiting, even if the ecosystem does not have the same quality as before. The Mi Publito Viajes stated that fishing and excursion trips are the most sensitive activities. Taking the environmental catastrophe in the Sanctuary into account, the excursion tours seem to be more sensitive to pollution than fishery in a short term of time. An increase in concentration lead to an immediate immigration of several types of birds (Marcotte 2006) and are supposed to act in the same way if the same scenario was repeated. According to UACH the fish will rather be affected in a long term of time than in a short term, and should therefore be ranked as less sensitive than the excursion tours. As mentioned above, the concentrations of the toxicant are divided into four different categories: very high, high, intermediate, low and very low. By taking the historical factor into account and by letting the stakeholders (Mi Pueblito Viajes and UACH) rank the vulnerability of the activities, the concentration intervals as listed in the table 5 was stated.

The activities' concentration dependence was described with a trade-off value (see section 3.5). At the trade-off concentration, the probability for success state was set to 50-50 in the conditional probability tables. Lower concentration was set to 100 % and higher to 0.

Table 5 The activities in the rivers, their trade-off in a short term of time, related to the concentration toxicant.

Activity	Trade-off concentration
<b>Rafting, Kayaking</b>	Very high
<b>Excursions</b>	Low
<b>Fishing</b>	Intermediate

### 4.2.2.3 Sea functions: Fish supply, shellfish and beach activities

The same procedure was made for the activities related to the sea. According to the stakeholders, the most important activities in the area are fishing and shellfish business. Also, about 20 000 tourists visit the village every year for beach activities and consume shellfish. The activities are illustrated in figure 18.

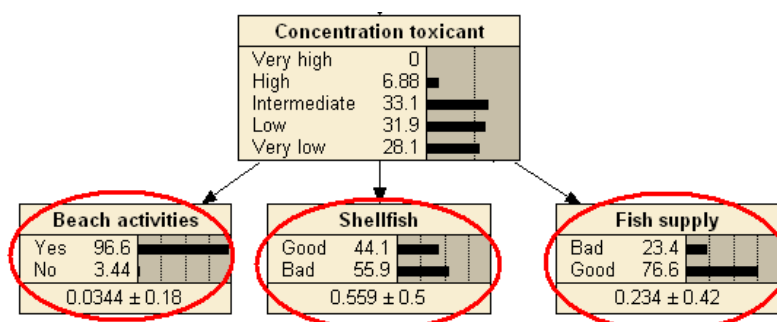


Figure 18 The sea functions and their parent in the short term sea network.

According to the fishermen in Mehuin and UACH, the activity that is most sensitive to the toxicants in a short term of time is probably the shellfish, closely followed by the fishery. None of the stakeholders think that the beach tourism would be affected by the probable concentrations in a short term of time. Table 6 shows the activities' trade-off value with respect to the concentration of the toxicant. As in the section concerning the activities in the rivers, the dependences were illustrated by a trade-off value. The probabilities for success state were set to 50-50 at the trade-off concentrations, 100 % success above the critical value and 0 below.

Table 6 The activities in the sea, their trade-off related to the concentration toxicant.

Activity	Trade-off concentration
<b>Shellfish</b>	Low
<b>Beach visitors</b>	Very high
<b>Fishery</b>	Intermediate

### 4.2.2.4 Biodiversity

The biodiversity is another important ecosystem function dependent on the concentration and illustrated in figure 19. As seen in 4.2.2.3 and 4.2.2.5, the concentration's impact on the ecosystem functions mentioned above was illustrated by a tradeoff value as described in 3.5. Biodiversity is a concept that depends on a high number of variables. Therefore, the relation between biodiversity and concentration should not be described with a trade-off value as the other ecosystem functions. A linear relationship was assumed to be a more suitable approximation, where an increase of one unit in concentration leads to a decrease of one unit of the biodiversity, see figure 20.

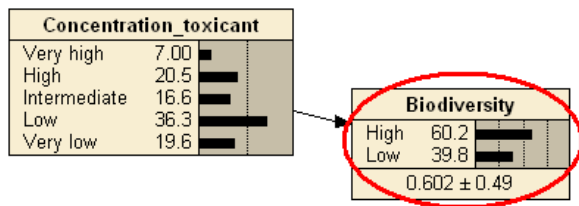


Figure 19 The node Biodiversity and its parent, which is similar in all four networks.

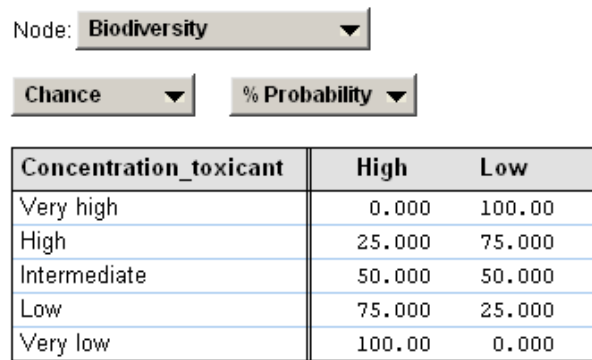


Figure 20 The node Biodiversity's linearly distributed conditional probabilities, similar in all four networks.

#### 4.2.2.5 Tourism

The tourism referred to in this report is the tourism dependent on the natural environment and its ecosystems. The parent-nodes impacting the tourism are the ecosystem functions listed by the stakeholders and discussed in sections 4.2.2.3 and 4.2.2.5. In figure 21 and 22, the node "Tourism" and its parents are illustrated.

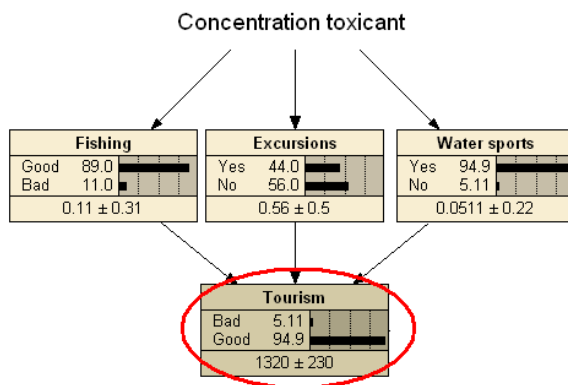


Figure 22 The node Tourism and its parent in the short term rivers' network.

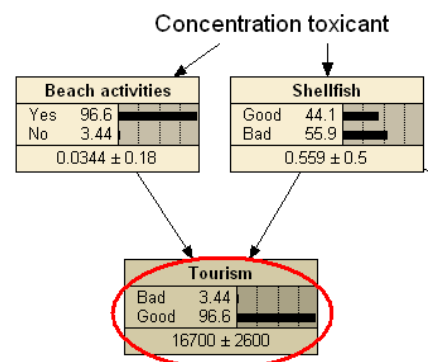


Figure 21 The node Tourism and its parent in the short term sea network.

#### Cruces and San Pedro Rivers

Every year lots of tourists visit the region and around 300 clients buy tours from the interviewed tourist company Mi Pueblito Viajes. Before the disappearance of the black necked swans, almost 100 % of the 300 clients were brought to the Sanctuary. This year only



three people asked for tours to Rio Cruces and the Sanctuary. The company still has the same number of clients but had to change locations and direction of activities when the Sanctuary got contaminated.

According to Valdivia city's webpage (Valdivia 2007), eight travel agencies, including Mi Pueblito Viajes, are operating in the area. To be able to estimate the annual number of visiting tourists to the watercourses, it is supposed that the seven remaining agencies have the same number of clients and distribution between activities as the interviewed company has. Also the same loss of clients going to the Sanctuary is assumed. This approximation leads to a number of 1600 tourists and a decrease in the visitors of the Sanctuary with approximately 99 % when the swans disappeared. The number of tourists visiting the watercourses in a short term of time is listed in table 7.

**Table 7** Estimated number of tourist visiting the locations per year.

Location	Number of tourists per year
<b>Cruces River</b>	1 600 (before contamination)
<b>San Pedro River</b>	1 600
<b>Mehuín</b>	20 000

As mentioned in section 4.2.2.3, the tourism in Cruces and San Pedro River are dependent on fishery, excursions, rafting and kayaking. In section 4.2.2.3 and 4.2.2.4, (table 5 and 6), the trade-off concentrations for each ecosystem functions were estimated. If the trade-off concentration for a certain function is reached, the activity can no longer be performed. Aiming to examine how the tourism business in the rivers would be affected by a discharge, the tourist company listed the percentage of the total number of tourists who visit the region every year, aiming to do the activities mentioned. The result is presented in table 8.

**Table 8** The trade-off concentration of the tourist activities and distribution in percent of tourists performing the activities.

Tourist activity	Trade-off concentration	Cruces River [%]	San Pedro River [%]	Mehuín [%]
<b>Rafting, Kayaking</b>	Very high	0	75	-
<b>Excursions</b>	Low	100	20	-
<b>Fishing</b>	Intermediate	0	5	-
<b>Shellfish</b>	Low			10
<b>Beach visitors</b>	Very high			90
<b>TOTAL</b>		100	100	100

Aiming to illustrate the possible change in number of visiting tourists to the rivers, equations 3 and 4 were used, where the importance of the ecosystem activity was weighed by multiplying the percentage given by the stakeholders to each activity (which was illustrated in table 8). The factors were then added and subtracted from the total number of tourists (see table 7). To be able to put out the probabilities for the tourist node states ("Good" and "Bad"), the node states have to be defined by absolute numbers. A greater tourist decrease than 30 % of 300 was supposed to be illustrated by the tourist node state "Bad" (0 to 210 tourists) and a decrease less than 30 % were illustrated by the node state "Good" (210 to 300 tourists).

The calculation was performed for all scenarios and the results were compared to the accepted number of tourists and deterministic conditional probabilities were allotted. The results of the calculations are shown in table 9.

$$T_{San\ Pedro} = 1600 - 1600(Rafting \cdot 0.75 + Excursions \cdot 0.20 + Fishing \cdot 0.05) \quad (3)$$

$$T_{Cruces} = 1600 - 1600(Excursions \cdot 1) \quad (4)$$

**Table 9 The node states for all scenarios concerning the tourism node.**

Rafting	Excursions	Fishing	Discharging point	Tourists	State
Yes	Yes	Good	San Pedro	1600	Good
Yes	Yes	Bad	San Pedro	1520	Good
Yes	No	Good	San Pedro	1280	Good
Yes	No	Bad	San Pedro	1200	Good
No	Yes	Good	San Pedro	400	Bad
No	Yes	Bad	San Pedro	320	Bad
No	No	Good	San Pedro	80	Bad
No	No	Bad	San Pedro	0	Bad
Yes	Yes	Good	Cruces	1600	Good
Yes	Yes	Bad	Cruces	1600	Good
Yes	No	Good	Cruces	0	Bad
Yes	No	Bad	Cruces	0	Bad
No	Yes	Good	Cruces	1600	Good
No	Yes	Bad	Cruces	1600	Good
No	No	Good	Cruces	0	Bad
No	No	Bad	Cruces	0	Bad

### Mehuín

According to the stakeholders, the tourist attractions in Mehuín are visiting the beach and eating shellfish. About 20 000 tourists visit the area every year, according to Gino Bavestrello and the village's webpage (Mehuín 2007).

All the stakeholders had different opinions concerning the relationship between the tourists visiting the village because of the shellfish, and the ones visiting the beach. Mehuín uphold that the fishery is extremely important for the tourist business, whereas UACH and APC argued that the main attraction for the visitors is the beach. During the visit to Mehuín, one could conclude that the tourist business based on shellfish is not well developed. Also according to Gino Bavestrello, only a few restaurants exist in Mehuín. This could confirm the independence between the 20000 tourists and the shellfish business. Therefore, 90 % of the tourists were estimated to visit the village mainly because of its beaches and the others mainly for eating shellfish, see table 8.

To illustrate possible tourist loss in Mehuín, equation 5 was used. The importance of the ecosystem functions was weighed by multiplying the percentages listed in table 8 to ecosystem function nodes. Since the program calculates with absolute numbers, the positive node states of the parents were allotted the number 0 and the negative node states 1. The

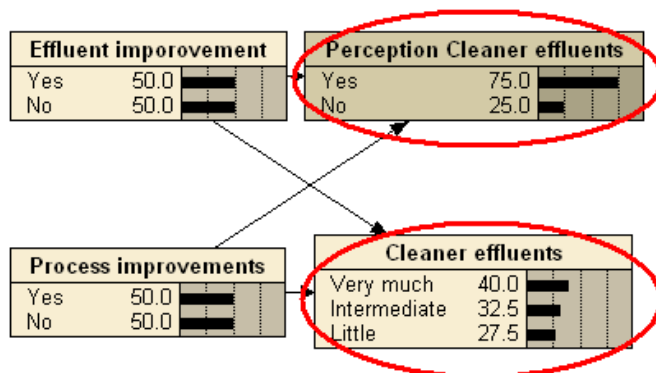
equation was written as given in the box below. The same 30 % boundaries were used for the node states “Bad” and “Good” as for the rivers, 0 - 14000 and 14000 - 20000 respectively.

$$T_{Mehu\grave{u}n} = 20000 - 20000(\textit{Shell fish} \cdot 0.10 + \textit{Beach visitors} \cdot 0.90) \quad (5)$$

```
Tourism (Shellfish, Beach_activities) =
minus(20000, mult(20000, plus(mult(0.90,
Beach_activities), mult(0.1, Shellfish))))
```

#### 4.2.2.6 Cleaner effluents and perception cleaner effluent

Two types of interventions of the effluent treatment are under investigation: First, exchange the tertiary treatment to using membrane technology and, second, let the waste water pass through an artificial wetland before discharging into the watercourse. Concerning the process change, APC appoints that there are also public wills of exchanging the bleaching process from an elementary chlorine free production to total chlorine free. Based on this information, two intervention nodes were added: “Process improvement” and “Effluent improvements” with the node states “Yes” and “No”, see figure 23.



**Figure 23** The nodes Perception Cleaner Effluents and Cleaner Effluents in the short term rivers’ network.

The interventions effect on the actual quality of the effluents was discussed with all stakeholders. The answers were very different and the opinion of the organizations (APC, San Pedro River Defense Committee and Mehuin Ocean Defense Committee) did not at all converge with the estimations made by the expert on UACH. Therefore, the node “Cleaner effluents” were divided into two nodes; “Cleaner effluents” and “Perception Cleaner Effluents”. “Cleaner effluents” is supposed to reflect the actual effect of the interventions and “Perception cleaner effluents” illustrates how the public *perceives* the effects.

### Cleaner effluents

This node is the same for all watercourses and time perspectives, since the interventions are realized inside the mill and are not affected by the recipient. Further, the effluent quality is not time dependent.

The node states of “Cleaner effluents”; “Much”, “Intermediate” and “Little” are qualitative states which reflect the improvements in the effluent qualitatively. The outcome is relative and based on the current effluent quality. Since there is no effluent improvements implemented today, the current quality of the effluents are defined as bad and in the state “Little”. Based on this, the scenarios were ranked by UACH. Three nodes states were preferable, since two nodes states (without the intermediate) would give the observer of the network the impression that the nodes reflect the extent of quality improvements. It is the probability of good/bad/intermediate effluent quality that the node refers to.

Concerning the effectiveness of the interventions, UACH think that the artificial wetland would be the most interesting measure to realize. Since no one knows what actually caused the problems in the wetlands, the outcome of the two other interventions is quite uncertain, because they both treat specific compounds. However, those two methods would decrease the levels of these compounds, which also are good for the ecosystems but maybe does not treat the specific problem. Therefore, the best effect would be achieved if all interventions were put into practice, effluent improvements the second best and the process chance on third place (see figure 24).

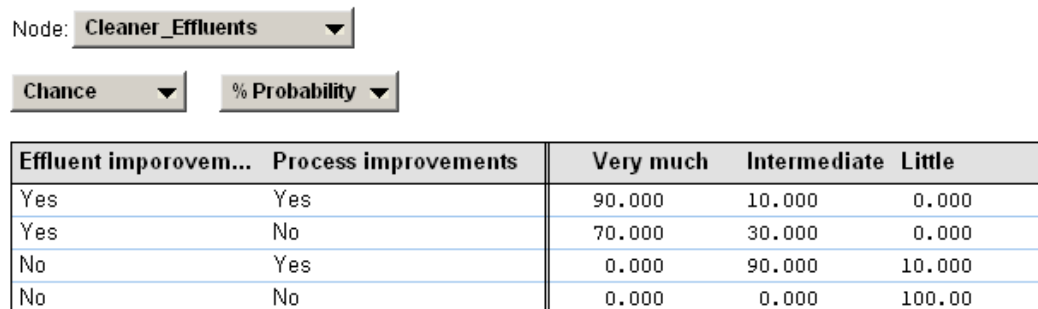


Figure 24 The conditional probability table of the node Cleaner effluents.

### Perception cleaner effluents

The node “Perception cleaner effluent” is supposed to reflect how people who are concerned about the discharging point *percept* the effects of the waste water quality measurements. The purpose of this node is to create an intermediate factor between the interventions and the node “Public concern”, described in section 4.2.3.1. Since other factors are supposed to affect the long term perspective of the public concern, this node will only be present in the short term network.

According to the stakeholders, the public opinion regarding the interventions varies a lot, because of lack of information. For the people in Valdivia (not in Mehuin), the perception seems to be more dependent of *any* measure, than *which* type of intervention that is put into practice. Therefore, the node “Perception cleaner effluents” is set to be a dependent node; independent of the intervention that is realized, the effluent is believed to be cleaner (See figure 25).

In Mehuin, on the other hand, none of the stakeholders believe that any improvement would make a difference in the inhabitants' perception of the effluents and the node is therefore deleted in the sea networks. How important these public believes are for the public concern is discussed under Public concern (4.2.3.1).

Node: Perception\_Cleaner\_Effl

Deterministic Function

Process improvements	Effluent improvem...	Perception Cleaner effluents
Yes	Yes	Yes
Yes	No	Yes
No	Yes	Yes
No	No	No

Figure 25 The deterministic conditional probabilities for the Perception Cleaner Effluents node.

#### 4.2.2.6 Decision CONAMA

CELCO-Arauco has asked for permission to increase its production to 550 ton/year (full production) (oral comm. Pablo Baraño, 2007-10-19). The node "Decision CONAMA" illustrates the probability that CONAMA would permit CELCO-Arauco increase the production to 550 tons per year full production), *after* the decision regarding discharging point has been made. A, for CELCO-Arauco, positive decision, is illustrated with the node state "Yes" and the negative with the node state "No".

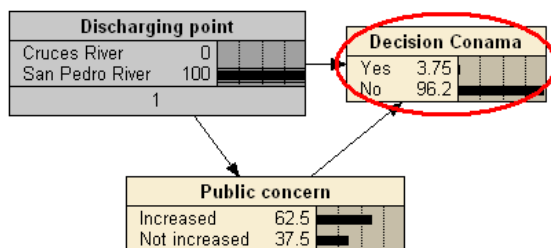


Figure 26 The node Decision CONAMA and its parents in the short term rivers' network.

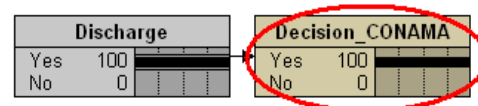


Figure 27 The node Decision CONAMA and its parents in the short term sea network.

#### Cruces and San Pedro Rivers

As seen in figure 26, the node is dependent on the public concern and the discharging point itself. Concerning Cruces River the outcome of this node was clear from the beginning. CONAMA have decided that CELCO-Arauco will not get the permission if the discharging point is not moved. In other words, the probability of a positive decision is zero in a short period of time, if CELCO-Arauco keeps on discharging into Cruces River.

San Pedro River is not seen as a good and probable alternative of any of the stakeholders and the reason for choosing San Pedro River would be due to lack of other alternatives. All stakeholders agreed that the probability of a positive decision would be higher than for Cruces River, but still very low. Besides, if the public concern would increase, the decision would definitely be negative. The conditional probabilities are presented in figure 28.

Node: **CONAMA\_decision** ▼

Chance ▼    % Probability ▼

Public concern	Discharging point	Yes	No
Increased	Cruces River	0.000	100.00
Increased	San Pedro River	0.000	100.00
Not increased	Cruces River	0.000	100.00
Not increased	San Pedro River	10.000	90.000

Figure 28 The conditional probabilities for the node Decision CONAMA in the short term rivers' network.

### Mehuín

As seen in figure 27, the decision is only dependent of the discharging point. In this case, the public concern is not seen as a parent of the node, because the people in Mehuín have expected an increase in the production, in case of discharging into the sea. In other words, if Mehuín lose the battle concerning the discharging point they are aware of the possible production increase. Almost every stakeholder agreed that the probability for a positive decision is very high if the effluents would be discharged in Mehuín. CONAMA claimed that such prediction cannot be made until an environmental impact assessment has been presented.

#### 4.2.2.7 Increased production CELCO

This node illustrates the dependence between CONAMA's decision and an increased production. CELCO-Arauco has made clear that one of the company's objectives is to go up to full production. Therefore, the probability for an increased production in case of a positive decision is 100 % and the node is directly dependent of the node "Decision CONAMA". There are no differences between the watercourses and the node has two node states; "Yes" and "No".

#### 4.2.2.8 Fishermen

The node "Fishermen" illustrates the number of fishermen performing a specific activity. 20 % of 300 fishermen are supposed to mainly catch shellfish and 80 % fish, see figure 29. This is illustrated using equation 6. The same relationship is assumed in both short and long term.

$$Fishermen = 300(0.80 \cdot Fish\ supply + 0.2 \cdot Shellfish) \tag{6}$$

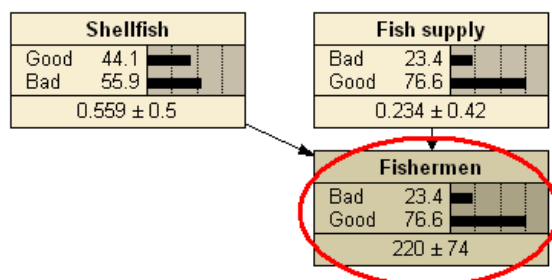


Figure 29 The node Fishermen and its parents, which is similar for both sea's networks.

### 4.2.3 Management Objectives

The management objectives are the objectives of the study, this is stated by the stakeholders and are impacted by management the interventions (Discharging point, Process improvements, Effluent improvements and Pipe length). By changing interventions in the BN, the impact on the management objectives can be studied.

#### 4.2.3.1 Public concern

The node “Public concern” reflects the concern of the people directly affected by the decision and its node states “Increased” and “Not increased” are defined by comparing the outcome to the current public concern. See figures 30 and 31.

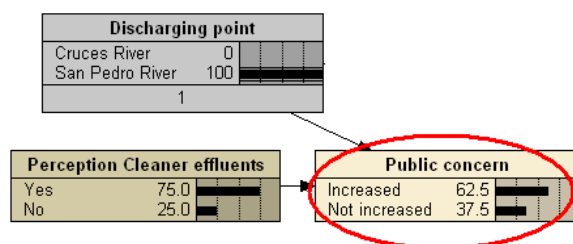


Figure 30 The public concern node and its parents in the short term rivers' network.

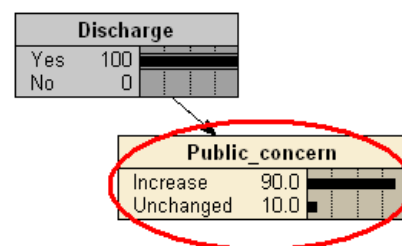


Figure 31 The public concern node and its parents in the short term sea network.

#### Cruces and San Pedro Rivers

The public concern is a child of two nodes; the discharging point itself and the perception of the effluent improvements. All stakeholders agreed that those two were the main factors, but had different opinions about in which degree the nodes are affecting the public concern. APC argued that the improvements would not affect the public concern much, because of lack of faith in CELCO-Arauco, but San Pedro River Defense Committee gave the discharging point a subordinated position. Aiming to add probabilities to the conditional probability table, the different opinions had to be converged. The stakeholders were requested to rank the different scenarios after their likelihood and also say anything about their probability. The probabilities described with words, for example “High, “Very high” were translated by using the table in 3.5. The answers are listed in table 10.

Table 10 All scenarios of the node public concern and the probabilities of the node's success state. The estimations made by all stakeholder and the mean value are listed.

Discharging point	Perception Cleaner Effluent	CELCO-Arauco	APC	San Pedro River Def. Comm.	UACH	MEAN
<b>Cruces</b>	Yes	50	50	90	70	65
<b>San Pedro</b>	Yes	30	50	70	30	45
<b>Cruces</b>	No	30	30	30	50	35
<b>San Pedro</b>	No	10	30	10	10	15

A mean value of each scenario was calculated and is showed in the conditional probability table in figure 32. Another way to do this would have been weighing the number of people within in each stakeholder group when calculating the mean value, as Cain (2001) does. Since

the opinions regarding the public concern are not anything these stakeholder groups have as a common opinion, these thoughts are supposed to be highly personal and using the number of members would not lead to more reliable numbers.

Node: **Public\_concern** ▼

Chance ▼    % Probability ▼

Discharging point	Perception Cleaner effluents	Increased	Not increased
Cruces River	Yes	35.000	65.000
Cruces River	No	65.000	35.000
San Pedro River	Yes	55.000	45.000
San Pedro River	No	85.000	15.000

Figure 32 The conditional probability table of the node Public concern in the short term rivers' network.

### Mehuín

The public concern in Mehuín is not dependent on the perception of cleaner effluents, according to all stakeholders. The political situation in Mehuín is serious and the inhabitants' resistance against the mill and its effluents is complex and would not be affected by effluent improvements.

All stakeholders, except CELCO-Arauco were concerned about the social situation in Mehuín. They claimed that there is a high probability of increased public concern which also would probably lead to injuries as a result of riots, if the pipe would be installed. As in the upper section, there was a disagreement among the stakeholders to which extent the public concern would change if the discharging point would be moved to Mehuín. The respondents described the two scenarios after the probability of an increased public concern. The respondents' estimations are listed in the table below (see table 11). A mean value of 10 % of was calculated.

Table 11 The scenarios of the node public concern and the estimations made by all stakeholder and a mean value.

Discharging point	CELCO-Arauco	APC	San Pedro River Def. Comm.	UACH	MEAN	CELCO-Arauco
<b>The Sea</b>	30	0	0	10		10



### 4.2.3.2 Recreation

All stakeholders agreed that the most important factor for the recreation of the inhabitants and their wellbeing was dependent on the quality of the ecosystem. The respondents wanted to keep the nature as it is (or was before contamination) and preserve it to their children. Some of the stakeholders (Claudia Sepúlveda, Eduardo Jaramillo and Jorge Muller) appointed that the practices of water sports was popular and also visiting the beach, for example in Mehuin. The nodes are illustrated in figures 33 and 34.

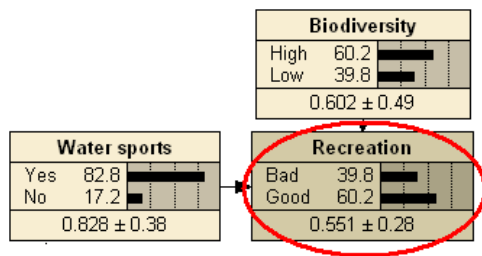


Figure 34 The Recreation node and its parents in the short term rivers' network.

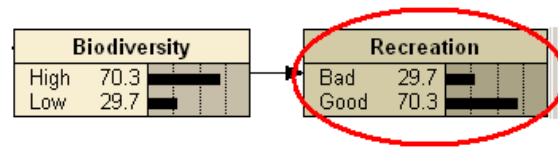


Figure 33 The Recreation node and its parents in the short term sea network.

#### Cruces and San Pedro Rivers

As mentioned above, the quality of the nature (“Biodiversity”), water sports and visiting the beach had the highest recreation value according to the stakeholders. The parameter “Beach activities” is not directly affected by the effluents in the rivers but is illustrated in the node Tourism in Mehuin. People enjoying water sports are also enjoying nature and the parameters are hard to separate when it comes to evaluating their influence on the recreation. Therefore, the recreation was illustrated by evaluating the “Recreation value”.

According to the stakeholders, the water sports had a subordinated role for the recreation, compared to the biodiversity, and were estimated to contribute with 20 % of the recreation value. Equation 7 was added to the node aiming to weigh the parameters against each other. As appointed before, the software works with absolute values. Therefore, the positive node states of the parents were given the number 1 and the negative node states the number 0. Using equation 7 written on the form illustrated in the box below, the output value of the Recreation node was given a number between 0 and 1. In lack of better options, the Recreation node’s node state “Bad” was defined for 0 - 0.5 and “Good” for 0.5 – 1.

$$\text{Recreation value} = \text{Biodiversity} \cdot 0.8 + \text{Water sports} \cdot 0.2 \quad (7)$$

```
Recreation (Biodiversity, Sports) =
minus(1, plus(mult(0.2, Sports),
mult(0.8, Biodiversity)))
```

Mehuín

According to the fishermen, the most important factor concerning the recreation in Mehuín was to maintain the ecosystems. Therefore, the recreation node was supposed to be dependent on only the biodiversity node. The parameter Biodiversity is very complex and the term recreation is a subjective factor. Therefore, the relationship was supposed to be linear and deterministic. The definition of the node states was the same as for the rivers; 0 – 0.5 illustrated a bad recreation value and 0.5 – 1 a good.

4.2.3.3 Employment opportunities

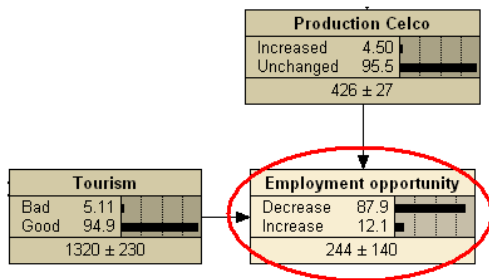


Figure 36 The node Employment opportunities and its parents in the short term rivers' network.

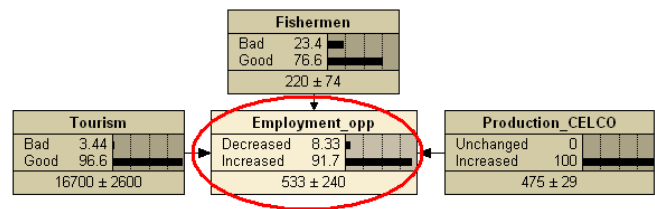


Figure 35 The node Employment opportunities and its parents in the short term seas' network.

Cruces and San Pedro Rivers

The employment opportunities affected by the discharging points are thought to be the tourism and the employment opportunities on CELCO-Arauco and the ones an increased production would contribute with (see figures 35 and 36).

According to CELCO-Arauco and their homepage, 350 persons are employed in the production and therefore affected of an increased or decreased production. CELCO-Arauco assumes that the relationship between employees and production is linear. In other words, an increase by 20 % in production would lead to 20 % new employment opportunities.

CELCO-Arauco wants to increase the production from 420ton per year to 550 ton per year, which is full production. The number of employees would in such case increase from 350 to 420. Since the function is supposed to be linear, the coefficient was estimated to be 0.77. See equation 8.

The tourist company has ten employees and 300 clients, which means 30 tourists per employee. This approximation is supposed to be linear with the coefficient 0.033. See equation 9. Equation 8 and 9 were put together to illustrate the number of employees, see equation 10.

$$Employment\ opportunities_{CELCO} = production \cdot 0.77 \tag{8}$$

$$Employment\ opportunities_{Tourism} = (Number\ of\ tourists) \cdot 0.033 \tag{9}$$

$$Employment\ opportunities = production \cdot 0.77 + (Number\ of\ tourists) \cdot 0.033 \tag{10}$$

First, the formula was used to calculate the best and worst case and also business as usual. If both the maximal employment opportunities on the company and in the tourists business are achieved, the best case was calculated to be 473 employees. If the production is as it is today, and the tourism decreases, 323 work opportunities would exist. Business as usual contributes with 403 job opportunities. Therefore, the node state “Decreased” is defined for 323 - 376 individuals and “Increased” for 376 - 476. The equation was written on the form illustrated in the box below.

```
Employment_opp (Tourism, CELCO_Production) =
plus(mult(0.0333, Tourism), mult(0.77,
CELCO_Production))
```

### Mehuín

The job opportunities in the Mehuín case depend on three node parents, as seen in figure 36 and illustrated by equation 11.

$$\text{Employment opportunities} = \text{Fishermen} + 0.0083 \cdot (\text{Number of tourists}) + 0.77 \cdot \text{Production} \quad (11)$$

As mentioned above, 300 fishermen are working on daily basis in Mehuín. The number of fishermen is not supposed to increase because the catch is regulated. On the other hand, the fishermen are worried that a continuous discharge would have negative effect on the fishery. Since the node “Fishermen” is giving the predicted number of fishermen, the node is basically added to the other two job opportunities.

The node Fishermen was estimated to be impacted by the node “Shellfish” to an extent of 20 % of the total load of work, as seen in section 4.2.2.8. The fisheries are small scale companies, often family business, which sells its catch of shellfish to tourists on the market or in restaurants. Generally, the man in the family owns the family company and go out fishing and the wife and the children sells the fish on the market. Since 20 % of 300 individuals catch shellfish, approximately the double, 40 %, of 300 people sells it. This leads to 120 people. Therefore, 20 000 tourists contribute with 167 job opportunities (20 000 / 120) and the relation was supposed to be linear with a coefficient of 0.0083. The production rate was supposed to contribute with the same number of employees as for Cruces and San Pedro Rivers, since the same forecasts are applied.

The node state definitions were allotted after estimating the best case and business as usual. If the tourism was good (167 employees), 300 fishermen were working and CELCO-Arauco increased its production (420 employees), 887 job opportunities would exist. Today, the fishery contributes with 300 persons, 167 people are activated within the tourism business and CELCO-Arauco has 350 employees, which leads to 817 employment opportunities. Therefore, the node state “Decreased” was defined as 0 - 817 and “Increased” as 817 - 887. In Netica, the equation was written on the same form as for the rivers and illustrated in the box below.

```

Employment_opp (Tourism, CELCO_Production) =
plus(mult(0.0333, Tourism), mult(0.77,
CELCO_Production))
    
```

### 4.3 Long term Bayesian networks' node description

In the following section, a description of the nodes in the long term of time is found. As in the short term section, the variables are divided into three parts; Management Interventions, Intermediate Factors and Management Objectives.

#### 4.3.1 Management Interventions

The same management interventions as in the short term BN can be chosen as input in the long term network (see section 4.2.1). In addition, the short term result has to be evaluated by the manager and used as an input variable "Result Short Term" in the long term BN. The node states for "Result Short Term" is "Good" and "Bad".

#### 4.3.2 Intermediate Factors

The intermediate factors are listed and described below.

##### 4.3.2.1 Concentration toxicant

The concentration of toxicant has the same definition in al long term perspective as in short term. As in the short term network, the conditional probabilities were allotted in cooperation with the experts, UACH. For node state definitions, see section 4.2.2.1. The nodes are illustrated in 37 and 38 and the differences between the short and long term cases are described below.

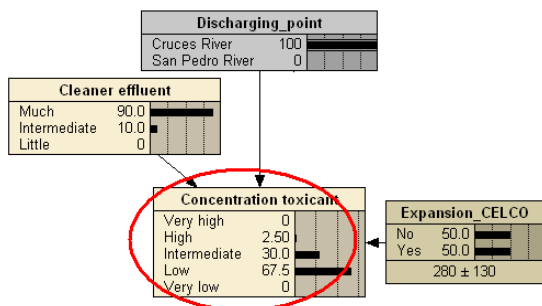


Figure 38 The node Concentration toxicant and its parents in the long term rivers' network.

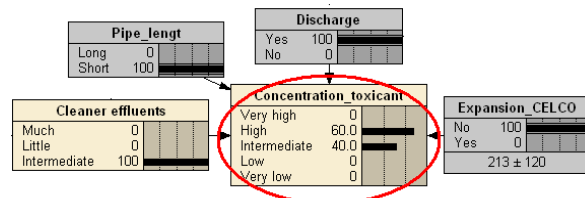


Figure 37 The node Concentration toxicant and its parents in the long term sea network.

### Cruces and San Pedro Rivers

As in the short term perspective, the node “Concentration toxicant” has four parents. The only difference between the two time perspectives is the parent “Expansion CELCO”. This node refers to a reconstruction of the mill and can be compared to a production increase as discussed in the short term section. It is hard to predict if an expansion will be of interest and it is impossible to say how much the production would increase. Therefore, an increase in the same magnitude as the short term production increase is assumed, which leads to the same concentrations are held for both long and short term of time.

### Mehuín

When it comes to the sea, the node “Expansion CELCO” has been added, since UACH appointed that the effect of an increased production cannot be neglected. UACH were requested to rank the importance of the factors affecting the toxic concentration. The pipe length was the most important, followed by the treatment of the effluents. The increase in the production was assumed to have least impact, as for Cruces and San Pedro Rivers. Therefore, the scenarios with no increase in the production were believed to generate the same concentrations as in the short perspective, which means that the best case (long pipe, all effluent interventions and carried out and no increase in the production) was assumed to be a 100 % success. Since the impact of an increased production was not believed to be very big, the probable concentrations were in a first step dislocated towards higher concentrations with units of 10 %, see figure 39.

Node: **Concentration\_toxicant** Apply Okay

Chance % Probability Reset Close

Discharge	Expansion_CELCO	Pipe_lengt	Cleaner effluents	Very high	High	Intermediate	Low	Very low
Yes	No	Long	Much	0.000	0.000	0.000	0.000	100.00
Yes	No	Long	Little	0.000	0.000	0.000	50.000	50.000
Yes	No	Long	Intermediate	0.000	0.000	0.000	100.00	0.000
Yes	No	Short	Much	0.000	0.000	50.000	50.000	0.000
Yes	No	Short	Little	0.000	0.000	100.00	0.000	0.000
Yes	No	Short	Intermediate	0.000	50.000	50.000	0.000	0.000
Yes	Yes	Long	Much	0.000	0.000	0.000	10.000	90.000
Yes	Yes	Long	Little	0.000	0.000	0.000	60.000	40.000
Yes	Yes	Long	Intermediate	0.000	0.000	10.000	90.000	0.000
Yes	Yes	Short	Much	0.000	0.000	60.000	40.000	0.000
Yes	Yes	Short	Little	0.000	10.000	90.000	0.000	0.000
Yes	Yes	Short	Intermediate	0.000	60.000	40.000	0.000	0.000
No	No	Long	Much	0.000	0.000	0.000	0.000	100.00
No	No	Long	Little	0.000	0.000	0.000	0.000	100.00
No	No	Long	Intermediate	0.000	0.000	0.000	0.000	100.00
No	No	Short	Much	0.000	0.000	0.000	0.000	100.00
No	No	Short	Little	0.000	0.000	0.000	0.000	100.00
No	No	Short	Intermediate	0.000	0.000	0.000	0.000	100.00
No	Yes	Long	Much	0.000	0.000	0.000	0.000	100.00
No	Yes	Long	Little	0.000	0.000	0.000	0.000	100.00
No	Yes	Long	Intermediate	0.000	0.000	0.000	0.000	100.00
No	Yes	Short	Much	0.000	0.000	0.000	0.000	100.00
No	Yes	Short	Little	0.000	0.000	0.000	0.000	100.00
No	Yes	Short	Intermediate	0.000	0.000	0.000	0.000	100.00

Figure 39 The conditional probability table for the node Concentration toxicant in the long term sea network.

### 4.3.2.2 Ecosystem functions

The tourist company Mi Pueblito Viajes and the fishermen in Mehuin identified the most important ecosystem functions on which their work is dependent, see figure 40 and 41.

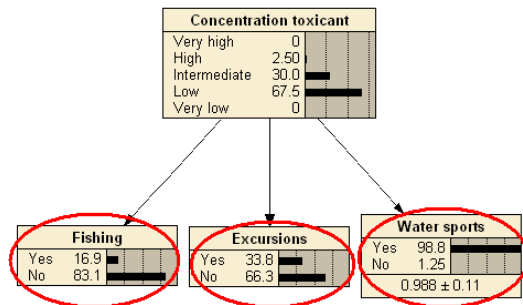


Figure 41 The river functions in the and their parent in the long term rivers' network.

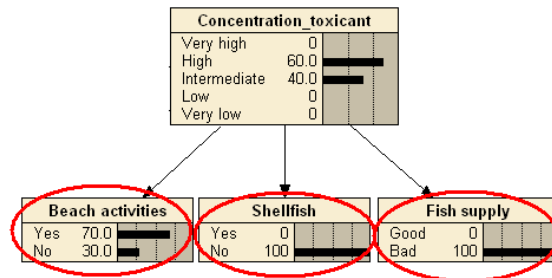


Figure 40 The sea functions in the and their parent in the long term sea network.

#### Cruces and San Pedro Rivers: Fishing, excursions and water sports

When looking at the activities in the watercourses in a long term of time, two aspects must be taken into account; if there are any changes in activities and if the concentration of the toxic compound affects the activity in another way than in the short perspective. For example, the time perspective is an important factor when it comes to exposure to toxicants.

As mentioned in the short term section, UACH did not think the fishery would be affected immediately, but in a longer perspective. Therefore, the trade-off concentration for the activity “Fishing” has got a lower value than in the short perspective. Since excursion trips are based on the visible ecosystem functions, the biggest threats (for example emigration of birds) are thought to be in the short perspective and maintained in a long term of time. By letting Mi Pueblito Viajes rank the toxic sensitiveness of the activities the trade-off concentrations in table 12 was stated. Drinking water is discussed in section 4.3.3.4. The probabilities were allotted with the trade-off method, described in section 3.5.

Table 12 The activities in the rivers, their trade-off in a long term of time, related to the toxicant concentration.

Activity	Trade-off concentration
<b>Rafting,</b> <b>Kayaking</b>	Very high
<b>Excursions</b>	Low
<b>Fishing</b>	Low-Very low
<b>Drinking water</b>	High

#### Mehuín: Fish supply, shellfish, contaminated fish and beach activities

Concerning the sea, the same ecosystem functions as in the short term section were listed by Mehuín Ocean Defense Committee and the same node states were used: Beach activities (“Yes”/“No”), Shellfish (“Yes”/“No”) and Fish supply (“Good”/“Bad”).

The difference between the short and the long term models were the fish supplies' concentration dependence. The toxic compound is not known and some stakeholders claim that it is persistent organic pollutants and other thinks heavy metals were the reason for the environmental catastrophe. However, both of these groups of compounds are known for causing long term effects in fish and the concentration for effects in the fish supply should, according to UACH be significantly lower than in the short time model.

The activities mentioned in a short term, were thought to be the maintained even in a longer perspective. Since the shellfish were affected already in the short time perspective, the trade-off concentration is supposed to be the same. Concerning the beach activities' concentration dependence, it is not thought to change in a long term of time. The beach tourists are temporary visitors and the time perspective would therefore not lead to more intoxications or health effects than in a shorter perspective that could have made the tourists choose another place. The trade-off concentrations are shown in table 13. The probabilities were added to the conditionally probability tables, according to the trade-off method in section 3.5.

**Table 13** The activities in the sea model, their trade-off in a long term of time, related to the toxicant concentration.

<b>Activity</b>	<b>Trade-off concentration</b>
<b>Shell fish</b>	Low
<b>Fishing sea</b>	Low
<b>Beach activities</b>	High
<b>Fish contamination</b>	Low

#### **4.3.2.3 Biodiversity**

See "Biodiversity" in the short term section.

#### **4.3.2.2 Cleaner effluents**

See "Cleaner effluents" in the short term section

#### **4.3.2.3 Fishermen**

See "Fishermen" in the short term section.

#### **4.3.2.4 Decision CONAMA**

In the long term perspective, it is possible that CELCO-Arauco applies for constructing an even bigger mill. The decision will be made by CONAMA and the aim of the "Decision CONAMA" node is to illustrate the probability for such permission. All stakeholders were asked and all agreed that the short term result and the node "Discharging point" would impact the decision. Since the decision is thirty years ahead and the outcome and definitions of the "Short term result" node's states were hard to interpret, it was difficult for the stakeholders to estimate the probabilities for a positive decision. All stakeholders agreed that the short term result was the decisive parameter. Discharging into the sea was supposed to lead to a higher probability. The same probability of a positive decision was allotted to both of the rivers. The only thing all stakeholders were sure of was the probability for a positive decision if a good

short term was achieved in Mehuin, was 100 %. The estimated conditional probabilities are presented in table 14.

**Table 14** The conditional probabilities for the scenarios related to the long term node Decision CONAMA.

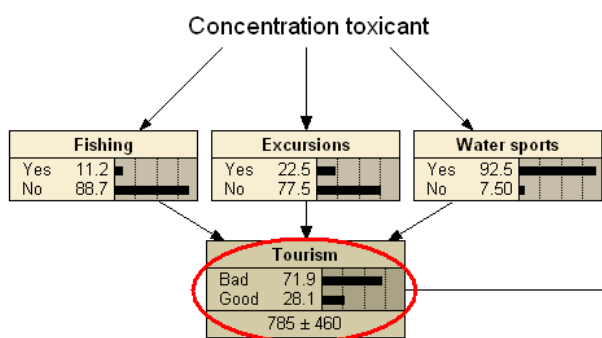
Watercourse long term	Short term result	Ranking	p (Positive decision)
Cruces River	Good	2	90
San Pedro River	Good	2	90
Mehuín	Good	1	100
Cruces River	Bad	5	0
San Pedro River	Bad	5	0
Mehuín	Bad	4	30

#### 4.3.2.5 Increased production CELCO

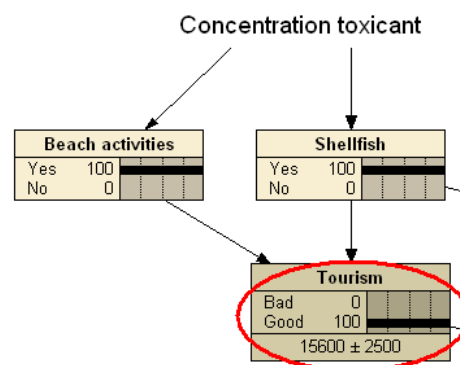
Like in the short time models, the “Increased production CELCO” is directly dependent on how CONAMA act in the case. A long term objective for CELCO-Arauco is to redesigning the mill. Therefore, the “Increased production CELCO” is a dependent node.

#### 4.3.2.6 Tourism

In this section, the tourism nodes are going to be discussed in a long term of time. The tourist nodes and their parents are illustrated in figure 42 and 43 for the rivers and the sea respectively.



**Figure 42** The Tourism node and its parents from the long term rivers’ network.



**Figure 43** The Tourism node and its parents from the long term sea network.

#### Cruces and San Pedro Rivers

All stakeholders agree that the tourism in the rivers has a great potential if the ecosystems are maintained or restored and the general opinion is that the number of tourists to the rivers and lake would probably increase with approximately 100 % (see table 15). The definition of “Good” and “Bad” tourism was the same as in the short term section, an increase or decrease with 30%, respectively (see section 4.2.2.6). In other words, more than 2100 visiting tourists per year was supposed to be “Good”.



Table 15 The estimated number of tourist in the locations in a long term of time.

Location	Estimated number of tourists per year
Cruces River	3 000 (without contamination)
San Pedro River	3 000
Mehuín	20 000

As in the short term section, the ecosystem functions were ranked with respect of the number of tourists devoted the activity. According to Roberto Salinas, the company planned to develop the fishery in the future. Therefore, the distribution among the activities was dislocated towards the fishing. The way of how the new distribution between the activities would change is hard to predict but as an estimation, ten percentage points was dislocated from the water sports and five percentage points from the excursions (see table 16).

Table 16 The estimated percentage of tourists performing the activities.

Activity	Cruces River [%]	San Pedro River [%]	Mehuín [%]
Kayaking	0	65	-
Excursions	100	15	-
Fishing	0	20	-
Shellfish	-	-	20
Beach activities	-	-	80
TOTAL	100	100	100

Aiming to illustrate the tourism node, the same procedure as in the short term section was used. By using equation 12 and 13, the percentages listed in table 16 were multiplied to the parents' node states and the result was compared to the definitions of good and bad tourism business. The result is seen in table f. and the deterministic probabilities were put in the node's conditional probability table.

$$T_{San\ Pedro} = 3000 - 3000(Rafting \cdot 0.65 + Excursions \cdot 0.15 + Fishing \cdot 0.20) \quad (12)$$

$$T_{Cruces} = 3000 - 3000(Excursions \cdot 1) \quad (13)$$

**Table 17 All scenarios of the Tourism node and the deterministic conditional probabilities.**

Rafting	Excursions	Fishing	Dis.point	Tourists	State
Yes	Yes	Good	S	1600	Good
Yes	Yes	Bad	S	1520	Good
Yes	No	Good	S	1280	Good
Yes	No	Bad	S	1200	Bad
No	Yes	Good	S	400	Bad
No	Yes	Bad	S	320	Bad
No	No	Good	S	80	Bad
No	No	Bad	S	0	Bad
Yes	Yes	Good	C	1600	Good
Yes	Yes	Bad	C	1600	Good
Yes	No	Good	C	0	Bad
Yes	No	Bad	C	0	Bad
No	Yes	Good	C	1600	Good
No	Yes	Bad	C	1600	Good
No	No	Good	C	0	Bad
No	No	Bad	C	0	Bad

### Mehuín

A lot of people visit Mehuín every year and the number is believed to stay constant. The tourism development in the village is, according to the fishermen, a question of making use of the high amount of tourists and developing the business; for example building hotels and shellfish restaurants. As in the section above, a 30 % loss in the number of tourists was seen as “Bad”, whereas less than a 30 % loss was seen as “Good”.

To illustrate the development of the tourist-business for example shellfish restaurants, ten percentage points are dislocated from the beach activities to the shellfish node. It is important to point out that the same groups of tourists aim to do both activities, but their interest space is moved towards the shellfish restaurants. To illustrate this, equation 14 was added to the tourism node, written as in the box below.

$$T_{Mehuín} = 20000 - 20000(\text{Shell fish} \cdot 0.20 + \text{Beach visitors} \cdot 0.80) \quad (14)$$

```
Tourism (Shellfish, Beach_activities) =
minus(20000, mult(20000, plus(mult(0.80,
Beach_activities), mult(0.2, Shellfish))))
```

### 4.3.3 Management Objectives

The management objectives are presented below.

#### 4.3.3.1 Public concern

The public concern depends on the short term result and the discharging point chosen (see figures 44 and 45). The stakeholders' opinions about how the nodes depended on their parents were divided. The same node state definitions were used as in the short term section (4.2.3.1).



Figure 44 The node public concern and its parents in the Rivers' long term network.

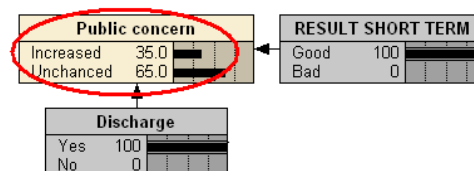


Figure 45 The node public concern and its parents in the Rivers' long term network.

#### Cruces and San Pedro Rivers

Concerning rivers and lake, San Pedro River Defense Committee and UACH insisted that the discharging point San Pedro River would upset the inhabitants the most, because of worries about contamination of the drinking water. Actions for the Swans, on the other hand meant that the discharging point did not matter at all if the short term result was known. The scenarios were ranked by the stakeholders and the probabilities were filled in. CELCO-Arauco insists that the effluents would not affect the watercourses and a negative short term result is impossible. To illustrate this, the same probabilities are allotted in both the positive and negative column. Table 15 illustrates the rankings made by the stakeholders; the allotted probabilities for success state (unchanged public concern) and the mean values, which were finally filled in the conditional probability table of the node.

Table 18 The scenarios for increased public concern in Mehuin are ranked and allotted a probability by the stakeholders.

Location	Short term result	CELCO-Arauco	Action for the Swans	San Pedro River Defense Committee	Univerisdad Austral de Chile	Mean value				
		Rank	[%]	Rank	[%]	Rank	[%]	Rank	[%]	[%]
<b>Cruces</b>	<b>Good</b>	1	70	1	70	1	90	1	70	70
<b>San Pedro</b>	<b>Good</b>	2	50	1	70	2	80	2	50	65
<b>Cruces</b>	<b>Bad</b>	1	70	4	40	3	50	2	50	50
<b>San Pedro</b>	<b>Bad</b>	2	50	4	40	4	10	4	10	25

#### Mehuin

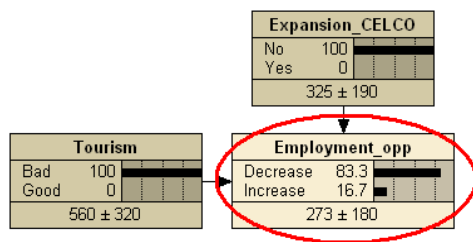
The same procedure was made for the public concern in Mehuin. Of course, all stakeholders agreed that a positive short term result would give a higher probability for the success state. Whether the discharging point will be located in Mehuin or not, is the most important factor for the public concern, according to Mehuin Ocean Defense Committee (see table 16). A mean value was calculated and filled in the conditional probability table.

**Table 19** The scenarios for increased public concern in Mehuin are ranked and allotted a probability by the stakeholders.

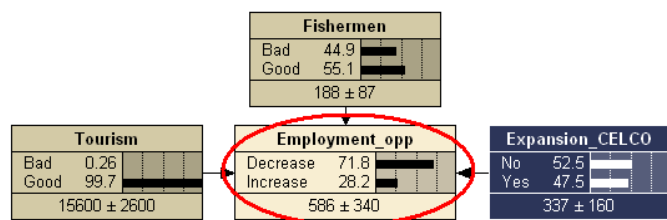
Short term result	CELCO-Arauco	Action for the Swans	San Pedro River Defense Committee	Univ Austral de Chile	Mehuin	Mean value
	<b>Rank</b>	<b>[%]</b>	<b>Rank</b>	<b>[%]</b>	<b>Rank</b>	<b>[%]</b>
<b>Good</b>	1	90	1	50	1	70
<b>Bad</b>	1	90	2	20	2	20

#### 4.3.3.2 Employment opportunities

As seen in figure 46 and 47, the same parents as in the short term section, are thought to impact on the number of employment opportunities. The same procedure concerning allotting the probabilities was made as in the short term result, both for the rivers and for the sea. The prediction concerning the expansion of CELCO-Arauco was hard for the stakeholders to estimate, why the same increase in production as in the short term of time is assumed for all watercourses.



**Figure 46** The node Employment opportunities and its parents in the long term rivers' network.



**Figure 47** The node Employment opportunities and its parents in the long term rivers' network.

#### Cruces and San Pedro River

The node state “Decreased” was defined as 0 - 376 and “Increased” as 376 - 530. The best case and business as usual was calculated aiming to define the states. Business as usual was estimated in the short term section (4.2.3.3) and lead to 403 job opportunities. The best case would occur if the production increased (420 employees) and the tourism developed well (100 job opportunities), which would give 520 jobs.

#### Mehuin

The best case concerning the jobs related to Mehuin, were estimated to give 1058 employment opportunities. Business as usual was estimated in the upper section (4.2.2.3) to 817 opportunities. Therefore, the node state “Decreased” was defined as 0 - 817 and “Increased” as 817 - 1058. According to Gino Bavestrello, Mehuin hoped to develop the work opportunities out of the existing number of tourists, in a longer perspective. Concerning the tourism business, the job opportunities were estimated to increase with 100 %. The relation was therefore supposed to be linear and with a coefficient of 0.0166 (0.0083 · 2). The number of fishermen and the production rate of CELCO-Arauco remained constant.

### 4.3.3.3 Recreation

See the short term section (4.2.3.2).

### 4.3.3.4 Culture of Mehuin

Since this node only concerns people in Mehuin, this node was based only on interview answers from Mehuin Ocean Defense Committee. The Culture of Mehuin is highly dependent on the fishery and according to Mehuin Ocean Defense Committee the culture and the spirit of the village would die in the same time as the fish supply decreases. To illustrate this, the node “Culture of Mehuin” with the node states “Stable” and “Unstable” was supposed to be a deterministic node, directly dependent on its parent “Fish supply”. See figure 48. The conditional probability table is seen in figure 49.

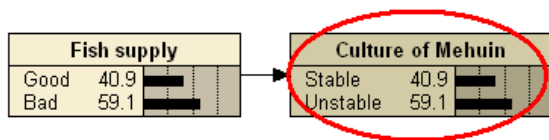


Figure 49 The Culture of Mehuin and its parent in the long term sea network.

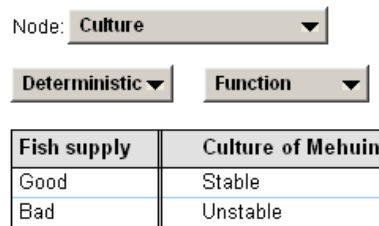


Figure 48 The deterministic conditional probabilities of the node Culture of Mehuin in the long term network.

### 4.3.3.5 Health

All stakeholders, except of CELCO-Arauco, were concerned about health effects, both concerning the rivers and the sea. The two node states were divided into “Affected” and “Unaffected”. See figures 50 and 51.

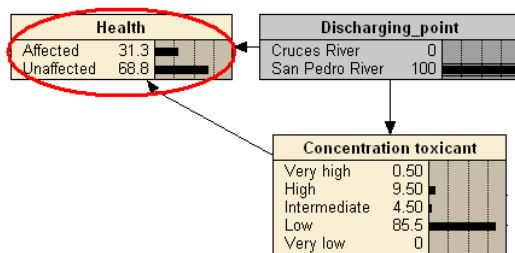


Figure 50 The health node and its parents in the long term rivers' network.

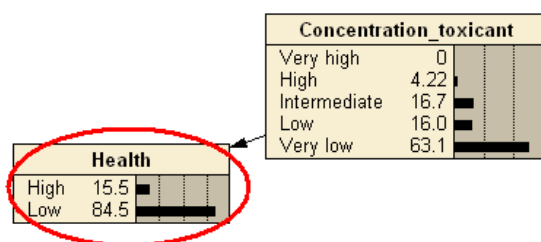


Figure 51 The health node and its parents in the long term sea network.

#### Cruces and San Pedro Rivers

The effects in the rivers are related to contamination of drinking water, since San Pedro River is a freshwater uptake. All stakeholders concerned about the problem, pointed out that the effect on the drinking water could be a problem in a longer term of time, although they thought the concentration had to be high to be a threat to human health. The node was not represented in the short term map, because none of the stakeholders were worried about this effect in the short perspective.

UACH was consulted as experts. The node was supposed to be affected by the toxicant concentration and whether the discharging point is a drinking water up take or not. If the watercourse was not a drinking water uptake (Cruces River), the probability for health effects was zero. Concerning San Pedro River, UACH had difficulties predicting the threat and how big the effects would be. Therefore, the probabilities for health effects in San Pedro River were linearly distributed (see figure 52).

Node: **Health** ▼

Chance ▼    % Probability ▼

Water_uptake	Concentration toxicant	Affected	Unaffected
Yes	Very high	100.00	0.000
Yes	High	75.000	25.000
Yes	Intermediate	50.000	50.000
Yes	Low	25.000	75.000
Yes	Very low	0.000	100.00
No	Very high	0.000	100.00
No	High	0.000	100.00
No	Intermediate	0.000	100.00
No	Low	0.000	100.00
No	Very low	0.000	100.00

Figure 52 The conditional probabilities of the node Health in the long term rivers' network.

### Mehuín

In Mehuín the possible health effects were related to consumption of contaminated fish. The Health node was supposed to be impacted by the concentration toxicant in the sea. There have been many studies performed concerning fish contamination and human health effects (see for example Järup (2003)), but since the compound released from the mill not is known, it is hard to use this information for estimating the effects. UACH suggested a linear relationship, which is shown in figure 53.

Node: **Health** ▼

Chance ▼    % Probability ▼

Concentration_toxicant	Affected	Unaffected
Very high	100.00	0.000
High	75.000	25.000
Intermediate	50.000	50.000
Low	25.000	75.000
Very low	0.000	100.00

Figure 53 The conditional probabilities of the node Health in the long term sea network.

#### **4.4 The Overall Result of Bayesian Network Modeling**

Since there are four networks and several interventions included in each network, many possible combinations of interventions exist and it would be impossible to present all combinations. Therefore, the overall result will be presented by selecting the most probable interventions according to the stakeholders and then compare the outcome of the management objectives. The same interventions will be selected for both short term and long term. In the long term result, the outcome of the short term result must also be taken into account.

CELCO-Arauco is investigating the effects of exchanging tertiary treatment to a membrane treatment, which is assumed to improve the effluents. The work is well advanced and the installation of membranes is very probable. Further, the Brazilian company CNTL is studying the effectiveness of leading the waste water through an artificial wetland before discharging it into the watercourse. This is thought to be very effective and also a probable solution, according to Eduardo Jaramillo. Based on this information, the management intervention “Effluent Improvement” is allotted the node state “Yes” in the Bayesian network.

The plan of exchanging the bleaching process from ECF to TCF is less probable, since the positive effects are not thought to be good enough to exceed the drawbacks. Neither Eduardo Jaramillo nor CELCO-Arauco or CONAMA, thinks the process change should be prioritized. Therefore, the management intervention “Process change” will adopt the node state “No”.

If the discharging point would be located in Mehuin, the intervention “Pipe length” has to be taken into account. The most probable intervention is to make a pipe longer than 2 km, why the node state “Long” will be adopted. To sum up, the management interventions’ node states used in the results is presented in table 20.

**Table 20 The node states of the management interventions used in the overall result.**

<b>Management intervention</b>	<b>Adopted node state</b>
Effluent improvement	Yes
Process improvement	No
Pipe length	Long

The interventions’ impact on the management objectives will be evaluated in the following section. The same interventions are assumed to be actual for both short and long term. The networks are found in Appendix 7-10.

##### **4.4.1 Short term result**

To achieve the lowest decrease in employment opportunities, the discharging point should be moved to San Pedro River (see table 21). The diversity in tourism activities is high in San Pedro River and the loss in job opportunities in the tourism business would therefore not be as big as in Cruces River or Mehuin. There is also a marginally higher probability of increased production if the discharging point is moved to San Pedro compared to Cruces River, which also contributes to job opportunities.

According to the model, the probability of loosing employment opportunities would be the same if Cruces River or Mehuin was chosen as discharging point. Despite that, the locations are very different and the job opportunities originate from different sources. The contribution

in job opportunities in Mehuin is due to the possibility of increasing the production and tourism development is the source of jobs in Cruces River.

Concerning public concern, the highest possibility for success state is in Cruces River. Since the people already live with the environmental disaster, a maintained collapsed ecosystem would upset less than an environmental disaster in another ecosystem, even if the Sanctuary would be restored.

The recreation supposed to reflect both the environment and the recreation value in the areas and is more or less dependent on the biodiversity of the ecosystems. The highest probability for unaffected recreation (and also high biodiversity) would, according to the model, be achieved if the discharging point would be moved to Mehuin, because of higher dilution. See table 21.

**Table 21** The probabilities for achieved management objectives in the short term result.

Management objective	Cruces River [%]	San Pedro River [%]	Mehuín [%]
<b>Employment opportunities</b>			
Increased	8.33	<b>12.1</b>	8.33
Decreased	91.7	87.9	91.7
<b>Public concern</b>			
Not increased	<b>65.0</b>	45.0	10
Increased	35.0	55.9	90
<b>Recreation</b>			
Yes	67.5	91.9	<b>96.2</b>
No	32.5	8.06	3.75

In the table 21, it comes clear that San Pedro River is the best discharging point regarding employment opportunities whereas Cruces River is most suitable concerning public concern and Mehuin is the best when it comes to recreation and biodiversity.

#### 4.4.2 Long term result

Except of the interventions mentioned above, the long term result depended on the short term outcome and the impact on the management objectives was examined for both good and bad short term result, which is presented in table 22 and 23.

In table 22 it comes clear that the minor loss in employment opportunities would be achieved if the discharging point was moved to Mehuin and the highest loss if the discharge into Cruces River would continue, given a good result is achieved in a short term. If the short term result is bad, Mehuin is still a lot better alternative according to the model, since the rivers contribute with a much higher loss in employment opportunities.



**Table 22** The node state probabilities for the management objectives in long term, given good short term result.

Management objective	Cruces River [%]	San Pedro River [%]	Mehuín [%]
<b>Employment opportunities</b>			
Increased	24.1	48.3	<b>64.8</b>
Decreased	75.9	51.7	35.5
<b>Public concern</b>			
Not increased	70.0	65.0	<b>90.0</b>
Increased	30.0	35.0	30.0
<b>Recreation</b>			
Yes	66.2	91.3	<b>96.0</b>
No	33.8	8.75	4.0
<b>Health</b>			
Unaffected	<b>100</b>	91.3	96.0
Affected	0	8.7	4.0
<b>Culture of Mehuín</b>			
Stable	-	-	88.0
Unstable	-	-	6.0

**Table 23** The node state probabilities for the management objectives in long term, given bad short term result.

Management objective	Cruces River [%]	San Pedro River [%]	Mehuín [%]
<b>Employment opportunities</b>			
Increased			
Decreased	8.3	8.3	<b>57.6</b>
	91.7	91.7	42.4
<b>Public concern</b>			
Not increased	<b>50.0</b>	25.0	20.0
Increased	50.0	75.0	80.0
<b>Recreation</b>			
Yes	55.0	80.0	<b>94.5</b>
No	45.0	20.0	5.5
<b>Health</b>			
Unaffected	<b>100</b>	80.0	94.5
Affected	0	20.0	5.5
<b>Culture of Mehuín</b>			
Stable	-	-	89.0
Unstable	-	-	11.0

Independent of the short term result, San Pedro River is supposed to contribute with the highest increase in public concern, which is due to the drinking water uptake. Concerning Mehuín, the high public concern in the short term result is thought to calm down. If the short term result is good, Mehuín is supposed to be the most suitable discharging point when it comes to public concern. On the other hand, if the short term result is bad, Cruces River is supposed to be the best place. A contamination of a new site would probably upset the citizen more, than maintain a low quality in Cruces River.

Concerning recreation and biodiversity, Mehuin is supposed to be the most suitable discharging point independent of the short term result, according to the model. Second best is San Pedro River followed by Cruces River, both also independent of the short term result.

The health effects apply to different factors in rivers and in the sea. The health effects in Mehuin concerns contaminated fish whereas it concerns drinking water in San Pedro River, which have to be taken into account when comparing the health effects. The greatest health effects are supposed to be achieved in Mehuin, followed by San Pedro River. Obvious, the best alternative concerning health effects is to discharge into Cruces River where no drinking water is taken.

When it comes to the preservation of the culture in Mehuin, there is no corresponding factor in the other watercourses to compare with. However, the long term effects are not supposed to be big, according to the model. That is due to the direct relationship between the culture and the fishery which is not assumed to be much affected.

To sum up, if the short term result is good and under given interventions, Mehuin is the most suitable discharging point when it comes to employment opportunities, public concern and recreation. The model indicates that there is a low risk of problems in the fishermen culture. Cruces River is not a source of human health risks and is the best alternative in that point of view. If the short term result is bad, also the public concern would be lower if the waste water keeps on discharging into Cruces River. The worst alternative in all cases is San Pedro River, according to the model.

### 4.5 Sensitivity analysis

To measure the management objectives' sensitivity to different input, a sensitivity analysis was made by using the built-in function in Netica. The sensitivity analysis was made for the node "Concentration toxicant", since this node have a central position in the network.

According to the results, the node "Cleaner effluents" had the biggest impact on the concentration of all nodes in the network. Aiming to achieve good values of the "Concentration toxicant" node, fining good in-data for the node "Cleaner effluent" should be prioritized. All nodes and their impact on the concentration node are listed in table 24.

**Table 24 The result of the sensitivity analysis by using Sensitivity to findings.**

<b>Node</b>	<b>Mutual Info</b>
Concentration toxicant	2.15849
Cleaner Effluents	1.20875
Fishing (tourism)	0.77492
Perception Cleaner Effluents	0.69042
Excursions	0.59268
Improvements effluents	0.53066
Tourism	0.47544
Sports	0.45833
Discharging point	0.41643
Recreation	0.34230
Biodiversity	0.34230
Improvements process	0.21791
Public concern	0.06126
CELCO Production	0.00218
CONAMA decision	0.00218
Employment opportunities	0.00025



## 5. Discussion

The results illustrated how the different management objectives are influenced by the management interventions. Since alternative discharging points is one of the interventions, the network can be used for modeling their impact on the factors important for the stakeholders, who are more or less dependent on the area where the discharging points would be located. Therefore, the result of the BNs can be used as a decision support system concerning the most suitable discharging point regarding ecological, social and economical perspectives.

### 5.1 Discussion concerning short term results

In the short term result (4.4.1), it became clear that all alternatives have benefits and drawbacks as discharging points, compared to each other. According to the model, San Pedro River was the most preferable concerning job opportunities, Mehuin had the lowest ecological impact and continue to discharge into Cruces River would have the least impact on the public concern. Two aspects of the result will initially be discussed: First, how should the result be interpreted and who is affected by it?

#### 5.1.1 Employment opportunities

An increase in employment opportunities means that more job opportunities exists after the implementation than before. Nothing is said about the *number of jobs*, the node just indicates an increase. The job opportunities consist today of fishermen, people working in the tourism business and at CELCO-Arauco. As the network is constructed, CELCO-Arauco uses the minimal number of employees possible today, which prevents a decrease in employment opportunities at the company. On the other hand, the tourism and the fishery are defined as fully functional, which means that only a decrease is possible. This node can therefore be misleading if the background of the construction not is known and should not be use as an absolute measure of actual employment opportunities. The nodes should rather be used to compare the magnitude of the interventions' impact on the job opportunities.

Further, the model shows the total number of employment opportunities in the area. Even if the network indicates a probable increase, this raise refers to a net increase, which could mean a decrease in job opportunities for some people. If the fishermen in Mehuin lose their income, it may not be possible for them to get a job at CELCO.

Finally, the node refers to direct job opportunities. Especially CELCO-Arauco and the tourism are related to a high number of indirect jobs, for example forestry, transports and consumption related to the tourism. These factors are not integrated in the model, but should not be excluded from the decision making process.

#### 5.1.2 Public concern

The parameter most difficult to quantify is probably the public concern. Since it is highly subjective, it is hard finding a good definition and "more concerned than today" was used. This opens for various interpretations and the magnitude of the public concern could be everything between a couple of more manifestations each year to a civil war in Mehuin. On the other hand, the scenarios were ranked by the stakeholders and since all discharging points

and other important factors were included, it would give a sufficient comparative evaluation of the alternatives impact on the node Perception cleaner effluents” node.

The public concern in Mehuin is thought to be higher than in the other watercourses. An important thing to have in mind is that much more people are concerned about the two rivers than about the fishery in Mehuin. This has not been taken into account in the model, but is an important factor to consider when using the BN.

### **5.1.3 Recreation**

The highest probability for maintained recreation is achieved in Mehuin. When discussing recreation in the model, the factor “Biodiversity” is important to consider since all recreation nodes are dependent or very dependent on the biodiversity node. The statement of a dependence is thought to be a good estimation but the manner the biodiversity and concentration are dependent is poorly illustrated in the model. Biodiversity is a highly complex concept and was very simplified in the network, where it was directly proportional to the concentration toxicant. All ecosystems have a different composition of species and have therefore different biodiversity and sensitivity to the toxicant (Walker *et al.* 2006).

Since the biodiversity is a very complex concept and describing biodiversity by adding more parameters would probably not have given a better model. More variables would have lead to that more uncertainty would have been included in the model and to a more complex, but probably not a better illustration (Mattsson 2000). The biodiversity node can indicate the magnitude of the toxicant concentration, which could be compared between the alternative discharging points and give an estimation of the discharging point having the least impact on the ecosystem. Further, the Sanctuary only has an age of 40 years and is therefore thought to be a lot more sensitive to pollution than the other ecosystems (oral comm. Ricardo Barra 2007-08-30), which not have been included in the BN. Also, the number of people concerned by the recreation varies between the locations and should be evaluated in the decision process as discussed under previous section.

## **5.2 Discussion concerning long term results**

The outcome of the long term result was easier to interpret than the short term result, since Mehuin contributed with the best result in four of five management objectives given good short term result and three of five given bad results. Despite that, there is of great importance to understand how the result is achieved and which limitations and estimations that have been made. The same discussion should be conducted for the long term objectives as for the short term perspective. Further, long term estimations are related to even higher uncertainties than the short term result, as the outcome area is larger.

Except of the management objectives in the short term result, two more factors were included concerning a long period of time; “Health” and “Culture of Mehuin”. Since the employment opportunities, public perception and recreation was discussed above, only the “new” management objectives will be discussed here.

### **5.2.1 Human health**

The health node is referring to various things in the rivers’ and the sea’s network and is also concerning different amounts and groups of people, which makes them hard to compare.

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Also, the uncertainty in this node is big since neither the compound nor the actual concentration is known. There have been many studies performed concerning health effects and contaminated fish (see for example Järup 2003), but the results is hard to apply on the case since the compound not is known and no data is available from Mehuin. This node contributes with one rational conclusion; Cruces River not is related to any direct health risks, since there are few activities performed in the watercourse which could affect humans.

According to the model, an increase in concentration contributes with a higher risk and because of lower dilution; San Pedro River is thought to be more riskful than the sea. In the reality, the probable biomagnification of the compound in fish would probable contribute to a higher health risk for people eating a lot of fish, compared to a toxicant directly accumulated in the human being.

### **5.2.2 Culture of Mehuin**

Concerning the culture in Mehuin, only the people in Mehuin are affected. Also, since no corresponding objective exists in the other watercourses, the result cannot be compared to anything else. Despite that, the culture is very important to the people in Mehuin and should therefore be represented, though it is subjective and hard to measure. Since the village is highly dependent on the fishery, a decrease in fish supply would probably impoverish the culture, which is illustrated in the model. This will be further discussed in section 5.3.

### **5.2.3 Result short term**

As mentioned earlier, the result in a longer perspective is affected by the short term result and is of course also dependent on the interpretation of that result. In other words, the outcome of the short term result depends on the network user's area of interest; if the observer is interested in the social questions, the economical or the environmental factors. The participants in this study had different opinions and valuations and would probably evaluate the short term outcome different. All interpretations and valuations originate in the person's own experiences, culture and risk perception (Teuber 1990), which is important to take into account when using the network as a decision tool. The criteria for valuation should be carefully described to provide transparent decision making.

## ***5.3 General discussion concerning results***

As discussed in section 5.1 and 5.2, the network model is based on many approximations and limitations and the actual values of the nodes may be accepted with some reservations. Despite that, the network gives a holistic picture of the system and the relationship between the most important parameters can be observed at the same time. The network indicates the best alternative discharging point gives certain circumstances, but how should the outcome be valued?

According to the model, the discharging point should be moved to Mehuin, providing that all management objectives are equally valued. The evaluation of results and decision criteria is a common problem further discussed by Belton and Stewart (2002). If the discharging point would be installed in Mehuin, it would probably affect the people living there negatively. On the other hand, the total benefit for the general public would probably be maximized, especially seen in a larger geographical perspective.

The forestry business is big in Chile and the mill is of great national importance and contributes with employment opportunities, taxes and national economic development (oral comm. Pablo Baraño 2007-10-17, oral comm. Enrique Suarez, CONAMA 2007-10-23). On the other hand, the production has a down-side; the effluents. Independent on discharging point, people will be affected even though to different extents. The general public wants to take part of the public welfare and sees the benefits of the industry, but is not prepared to handle consequences if it affects themselves. This is a common paradox referred to NIMBY (Not In My BackYard) referring to those who object to the siting of something perceived as unpleasant or potentially dangerous in their own neighborhood (equally to backyard) (van der Horst 2007). In such cases, stakeholders not numerous and marginalized in the society tend to be affected (Chung and Lo 2002). Strong parallels can be drawn to the fishermen in Mehuin. The solution of preferring the Mehuin site where the effluents will be discharged into the ocean can also be seen as a tragedy of the commons problem (Hardin 1968).

#### ***5.4 Bayesian network as a tool in environmental risk management***

IEC (1996) describes a standard for risk management, also discussed in 2.1. What is the BNs role in the risk management process? The discussion starts from the three main parts of the risk management process; risk analysis – whether there are any risks or not, risk evaluation – how large are the identified risks and what can be done to reduce them, risks and risk reduction/control – decision making concerning risk reducing measures and how to communicate the decisions to the involved stakeholders.

##### **5.4.1 Risk analysis**

The first step in a risk analysis is to decide what should be assessed (Suter 1993). In this study, the term management objective is used and could be compared to the concept endpoint in the environmental risk assessment model stated by Suter (1993). When a risk analysis concerns an environmental system, many possible endpoints could be of interest, which was the case in the problem concerning CELCO. By consulting stakeholders; the endpoints most important to the people (fishing, health etc.) could be stated. It is preferable to choose endpoints with relevance to the general public, aiming to find support for the outcome of the risk analysis (Suter 1993). By combining these objectives in a BN, the risk assessment can be put into its social context, ecological goals can be combined with social relevance and the analysis becomes holistic.

When all objectives for the study were stated and the network constructed, possible scenarios could be identified by varying the discharging point. The probability and standard deviation for a negative effect in a certain parameter is illustrated in the network and the risk could be estimated. By using the interactive network, the causal relationships between endpoints and threat are clearly shown, which contributes with a holistic understanding of the system.

Pollino *et al.* (2007) advocates the importance of a holistic approach when it comes to risk analysis and Nadkarni *et al.* (2004) appoint that an important benefit of the BN is the possibility to map the situation and get an overview. Previous studies concerning the CELCO-case are ambiguous and the BN provides a way of gather all accessible information, aiming to improve the risk analysis. As discussed above and stressed by Welp *et al.* (1996), the outcome of the BN should be used with carefulness and the network could rather be used as an initial analyzing method aiming to prioritize deeper studies, than used as a risk analysis method.



Understanding the system is essential when it comes to risk analysis (Pollino *et al.* 2007). The construction process itself provides a better knowledge about the problem and the integration of the parameters and people concerned (Cain 2001). During the work it became clear that all stakeholders had common interests even if they did not agree in many other key issues. They had also the same opinion concerning important impacting the factors, despite they disagreed about their mutual importance. One of the largest benefits of using a BN is the ability is to show the various perspectives of the involved stakeholders for all stakeholders, thus to improve mutual understanding. This has not have been within the scope of this project.

To sum up, using BN as a tool in risk analysis provides a holistic illustration of the situation, where the ecological risk can be put into its social context. Further, the method should be used with carefulness and are suitable as an initial risk analysis method which also gives the constructor a greater knowledge about the problem.

#### **5.4.2 Risk evaluation**

The interventions added to the network can be seen as risk reducing measures. By activating and deactivating the interventions in the model, the impact on the objectives can be illustrated and the effect of different risk measures can be evaluated. For example, if the *process improvements* are activated and *effluent improvement* deactivated the probability for a decrease in *employment opportunities* is higher compared to if the measures were activated the other way around. By doing this, the risk reducing measures can be ranked according to their effect on the management objectives.

According to Sjöberg (1999) and Renn (1998) the general public should be a part of evaluation of the risks, aiming to improve the acceptance of identified scenarios and finally final decisions. This is facilitated in a BN, since both experts and stakeholders are included in the network.

#### **5.4.3 Risk reduction/control**

In this step of the risk management process, decision between risk reduction measures (evaluated in the risk evaluation part) is a big part of the risk reduction/control, and further to communicate the decisions to the general public (IEC 1995).

The different combinations of management interventions, mentioned above, have to be evaluated so the “best” combination of interventions can be used to reach the objectives. As discussed in the 5.1.1-5.1.3, the best combination depends on which objective the decision maker values highest. Depending on the decision maker, the outcome will be evaluated differently, which of course also affects the decision. In the short term result, it became clear that all three discharging points had its advantages. All benefits could be the basis for choosing a certain discharging point, depending on who makes the decision; the fishermen in Mehuin want to preserve their culture and CELCO-Arauco value an increased production.

The node “Perception cleaner effluent” is an example on where experts and the public’s opinion diverge. If the decisions should be made based on the public opinion, any one of the improvement nodes could be chosen and leading to the same satisfaction, whereas the expert chose effluent improvement in front of the process measures. Should the decision be based on the experts’ knowledge or on the general public’s opinion?

As discussed in section 2.3.1, the general public's risk perception is understood as subjective and irrational. Renn (1998) discusses that it is possible that the biggest risks could be ignored and the damage bigger than necessary if the general public state the basis of the decisions. On the other hand, the experts could be biased toward certain decisions and Paté-Cornell (1996) stresses that political interest can have impact on the experts' judgments. For example, the environmental engineers at CELCO-Arauco work as environmental experts. If the company admit mistakes concerning the environmental safety, the mill has to be stopped immediately, which would be devastating for the company and its economy (oral comm. Claudia Sepúlveda, APC 2007-10-19). If these experts were consulted as experts in this case, it would certainly have affected the results and the decision making.

Renn (1998) advocates further that experts, the general public and decision makers not are against each other but their opinions have to be integrated in a scientific and transparent discussion. Since all stakeholders could be integrated in the BN, the model can be used as a basis of communication between stakeholder groups. By performing research not only deeply but also widely, for example by using a BN, unexpected points of contacts between stakeholder groups could be brought up and facilitating the decision making. This effect was seen in several of the interviews when the result from the first stakeholder consultations was shown to all respondents during on the second meeting.

It can be concluded that Bayesian Networks are easy to understand and therefore a good tool for communicating risks to the public (Welp *et al.* 2006). Since stakeholders' opinions were included in the network, the possibility for the public's acceptance of the risk related decision is bigger (Suter 1993). Pollino *et al.* (1998) finally states that when stakeholders are involved from the beginning to the end, the risk management process could become more transparent.

### **5.5 Biases**

The model clearly shows the mean value and the standard deviation of the data allotted to the conditional probability tables. On the other hand, the model does not show the underlying uncertainty in the model. Information carefully collected with high validity can be spread and show a higher standard deviation in the model than roughly estimated information with high reliability. This could mislead the decision maker to poorly interpret some nodes as more certain than others. This also have effect on the built in sensitivity analysis of the software, which only rely on the actual numbers added to the model. Therefore, it is important to collect data with as high validity as possible and to have a good knowledge about how the information is gathered.

Many people are affected by the decision in Valdivia and only the major stakeholder groups could be interviews. The stakeholder groups represented a huge number of people, which probably had other opinions and concerns than the respondents. Also, many of the questions crossed the limits for the common opinions of the stakeholder group and one single person had to represent the stakeholder group in questions maybe not representing the entire stakeholder group. Moreover, only one expert was consulted concerning environmental questions. Other people who could have worked as experts may have had different estimations than the ecological expert Eduardo Jaramillo.

The data collections are related to the stakeholder biases. Some of the interviews were performed in Spanish, which could have lead to misunderstandings. Since the interviews not were standardized, the interviews were not always performed in the same way, which could

have affected the result. The cultural aspects must also be taken into account, since the way of expressing for example worries and concerns differs in the cultures.

The way of letting the stakeholders rank the scenarios and then translate the explanations into numbers is related to high uncertainty. The first try was to let the stakeholders fill in the probabilities directly, which was shown to be too complex for the respondents. This method would also have been related to high uncertainty since the stakeholders probably perceive risks different from each other.

Some of the nodes were expressed with equations and estimations concerning job opportunities and future tourism was made. These numbers and relationships were approximated.



## **6. Conclusions**

The BN indicates that the discharging point should be moved to Mehuin. The result should be carefully interpreted and it is important to have an understanding of the information that the network is constructed upon. The analysis clearly shows that the best solution may not be the best solution if the system boundaries were expanded, thus then the similarity with the tragedy of commons syndrome.

The BN method can be used as a tool for risk management; from the risk analysis to communicating the final decision. The network should not be used as an automatic decision maker, but as a tool illuminating the interactions between certain interests, interventions and important parameters.



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## Appendix 1: Background

In April 1996, Chile's National Environmental Commission (CONAMA) accepted the Environmental Impact Study drafted by the company Celulosa Arauco y Constitución (CELCO-Arauco) for constructing a pulp mill near the San Jose de Mariquina in southern Chile, a one billion USD investment. The Environmental Impact Study was accepted if the company could guarantee proper treatment of the environmentally hazardous waste (Santiago times 1996).

According to the permission, CELCO-Arauco could choose between two alternative discharging points; discharging in the Pacific Ocean in the Maiquillahue Bay with two steps of effluent treatment or in Cruces River with a third step of waste water treatment. CELCO-Arauco chose the first alternative (Arauco 2007).

The Maiquillahue Bay is located 45 km north west from the factory, near the fishermen settlement Mehuín. When the discharging point was announced, the fishermen protested violently and COREMA took the final decision and made CELCO-Arauco locate the discharging point in Cruces River, with a third waste water treatment (Arauco 2007). Environmental groups such as Committee of Flora and Fauna, Greenpeace and the Chilean Ornithological Association protested and claimed that the effluents would affect the unique wildlife in the nearby Ramsar site; Carlos Anwandter Natural Sanctuary (Santiago times 1996).

The mill started operating in February 2004 and had big upstart problems with odors, noise and water pollution, which lead to convictions against CELCO-Arauco who had to pay fines and install technology for complete gas incineration (Marcotte 2006, Arauco 2007). A few months later the first signs came of a decrease in the population of, among other, the Black Necked Swan (Marcotte 2006). In November 2004, CONAMA turned to University Austral of Chile in order to examine the cause of the collapsed ecosystem (Jaramillo *et al.* 2007). University Austral of Chile and Jaramillo *et al.* studied the wetland for over five month and presented the results in April 2005 in the Final Report (UACH 2007). The study concluded that the death and immigration of the swans was caused by the disappearance of the prime producer *Enegia Densa*, which is the swans' main source of food (Jaramillo *et al.* 2007). Since the ground naturally contains a high amount of iron, aluminum ions from the third step of waste water treatment caused release of iron which covered the plants and inhibited the photosynthesis (oral comm. Eduardo Jaramillo 2007-10-23).

The conclusions regarding the cause of disappearance of the prime producer have been criticized by several instances and especially from the environmental compartment at CELCO-Arauco, who means that there is a missing link between the results and the conclusions in the report (oral comm. Miguel Osses 2007-10-17). Despite the drawbacks of the Final Report and because of lack of other data, CONAMA uses the Final Report as information base for making decisions in this case (oral comm. Enrique Suarez 2007-10-23). There is no scientific evidence that shows what actually caused the effects in the Carlos Anwandter Sanctuary and different theories exist apart from Final Report (2005). For example, Mulsow and Grandjean (2006) claims that sulfuric ions in the mill's effluents caused the death of the plant by causing loss of calcium bicarbonate and inhibit the plants extraction of carbon dioxide, which is necessary for the photosynthesis.

When CELCO-Arauco got their permission in 1996, many organizations were founded in order to prevent the installation of a pulp mill and to prevent ecosystem damage: Acción por los Rios (Action for the Rivers), which later became Acción por los Cisnes (APC, Action for the Swans) and is a citizens movement; Mehuin Ocean Defense Committee, an organization which consists of all communities living near the sea in Chile's tenth region and San Pedro River Defense Committee, which consists of tourist companies making tours to the Sanctuary and on San Pedro River. The organizations have split and changed direction several times because of internal conflicts of both internal and external influences. The number of members has decreased continuous since the start (oral comm. Pablo Barañaño 2007-10-17).

The transparency in the decision and actions from CELCO-Arauco has been of varying quality and the public resistance to the mill is high. Aiming to decrease public pressure, the company has established a local office in Valdivia, where the public can get information and ask questions. Also the CELCO-Arauco web page has a clear social/environmental profile. Despite these communication measures, the public confidence for both the company and the government is very low.

Because of lack of information, no transparency in the decisions and sometimes insufficient legislation, a lot of people are confused and have difficulties trusting both the company and the politicians (Claudia Sepúlveda, APC 2007-10-19, oral comm. Teresa Castro 2007-10-23). The environmental problems have converted to social conflicts and the situation in the area is more or less locked. Many environmental and ethical studies have been performed but very few linking this two areas together. The situation is not a strict environmental, political or social problem, it is a mix of all areas and more studies taking that into account is needed.

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## Appendix 2: Discharging points

There are three main reasons for moving the discharging point and both the government of Chile and CELCO-Arauco have interests in doing so. First, the Carlos Anwandter Sanctuary is a Ramsar-site and the government is obliged to protect and preserve the wetland (oral comm. Pablo Villaroell 2007-10-23). Second, CELCO-Arauco has applied for increasing the production to 100 % and CONAMA have declared that CELCO-Arauco will not get permission if the discharging point is not moved. Further, if the discharge in Cruces River continues, the truth about what really happened in the wetland will probably never be shown (oral comm. Pablo Barañaño 2007-10-17).

Three alternative points are proposed; discharge in Cruces River, San Pedro River or in the sea near the fishermen settlement Mehuin. San Pedro River is not seen as a probable choice, but according to Chilean legislation, all alternatives have to be examined before a decision can be made (oral comm. Enrique Suarez, CONAMA 2007-10-23).

### Point nr 1: Cruces River

As mentioned above, Cruces River is the current discharging point for the Valdivia mill. On its way to the sea, the river passes through a huge wetland, Carlos Anwandter Sanctuary. It was the settlement for many species of native birds, for example the Black Necked Swan, which is under threat of extermination. Because of its previous rich bird life the area became a Ramsar site 1981, which makes it to an area of international importance. The Sanctuary was formed after an earthquake 1960, which makes it to a relatively new ecosystem (Jaramillo *et al.* 2007). This, together with the fact that fresh water from the river is mixed with salt water from the sea are thought to make the ecosystem even more complex and be the reason for its special properties. The river is relatively narrow and its flow is about  $40 \text{ m}^3\text{s}^{-1}$  (oral comm. Eduardo Jaramillo 2007-10-23).

As mentioned above, many studies have been performed in the wetland and this is the only of the three alternative discharging points that data is available. According to CONAMA, the incomplete information is one of the reasons why a decision has not been made earlier.

Before the contamination, several tourist companies offered boat tours on the river and Carlos Anwandter Sanctuary for tourists to watch the swans and other native birds. When the swans immigrated and died, the tourist companies had to look for alternative rivers and activities and many of them moved their business to San Pedro River. Also farmers living nearby Cruces River use its water for watering their cattle and lands (oral comm. Claudia Sepúlveda, APC 2007-10-19).

### Point nr 2: San Pedro River

The second alternative is to discharge into San Pedro River. The river has different names along its way to the sea; San Pedro River upstream Valdivia, Valdivia River through city and Calle Calle River, downstream. Unlike Cruces River, San Pedro River has its outlet directly in the Pacific Ocean and that could be one of its benefits as a discharging point. A drawback is that Valdivia city takes 20 % of its drinking water from San Pedro River downstream the hypothetical discharging point. The river is a lot bigger than Cruces River.

When the Carlos Anwandter Sanctuary got contaminated and not longer served as a tourist attraction, the tourist agencies started to operate in San Pedro River instead. Therefore, a concerned group of San Pedro River is the tourist companies. Other interested persons are of course the citizens of Valdivia, taking the drinking water into consideration.

### **Point nr 3: Pacific Ocean – Mehuin**

Mehuin is a small fishing community with 1500 inhabitants, which runs small-scale fisheries. The people do not own their part of the sea but are renting it from the government according to the law “Area Natural de Manejo”, which gives them right to use the area for fishing under given circumstances.

Mehuin was the place that CELCO-Arauco purposed as the most suitable discharging point when the mill first was going to be constructed in 1996. The fishermen protested violently and CONAMA finally decided to move the discharging point to Cruces River aiming to calm the people in Mehuin. The objective of CELCO-Arauco has ever since been to move the discharging point because of economic benefits and the need to prove that they did not cause the effects in Cruces River.

Before changing the location of the discharging point, an Environmental Impact Study has to be handed in and accepted by COREMA. To be able to do the study, CELCO-Arauco has to collect samples from Mehuin but the fishermen have dispossessed the company every time. Without the Environmental Impact Study, the decision from COREMA cannot be made.

## **Appendix 3: Stakeholder presentation**

A short presentation of the selected stakeholders can be found in the following section.

### ***3.1 CELCO-Arauco***

CELCO-Arauco is one of the biggest forestry companies in South America, with several big mills and offices around the continent (Arauco 2007). The mill in Valdivia started operating in 2004 and was a one billion dollar investment. The Kraft pulping mill produces 550 000 tons per year and all is exported (Arauco 2007). The mill contributes with 259 direct and 745 indirect employment opportunities, according to the company itself.

### ***3.2 Action for the Swans***

The organization and politically independent citizen movement, Action for the Swans (APC) was formed in November 2004 when the environmental disaster in the Sanctuary of Carlos Anwandter first was announced. APC is a development from the group Action for the Rivers which was formed 1995 when the pulp mill project was started and the “Informe sobre el Proyecto Planta Valdivia de Celulosa Arauco y Constitución S.A” was announced. (APC 2007)

APC aims to inform the general public, the nation and the world about the magnitude of the ecological disaster and the environmental and health risks that a continued production contributes with.

### ***3.3 San Pedro River Defense Committee***

San Pedro River Defense Committee is a nongovernmental citizen movement, with the wellbeing of San Pedro River as common interest. The group consists of about 100 members represented of tourist companies, farmers and other people more or less dependent of the river's condition. Their aim is to spread transparent information about different threats to the ecosystem. At the moment, the plans of constructing a hydro electrical power plant upstream Valdivia is seen as the biggest (oral comm. Roberto Salinas 2007-10-22).

### ***3.4 National Environmental Commission (CONAMA)***

CONAMA is a governmental environmental institution and depends on the Chilean environmental ministry. It was created 1994 when the country's first environmental law (Ley N°19.300 de Bases Generales del Medio Ambiente) was shaped. The institution is represented in all regions in the country. Based on the law, CONAMA works with information, consultation, monitoring and communication of environmental questions (CONAMA 2007).

The important environmental decisions are not made by CONAMA. The Regional Environmental Commissions (COREMA) consists of representatives from other commissions (CONAMA included) and is responsible for making the regional environmental decisions. Depending on the properties of the decision, different commissions are included in COREMA (forestry, agricultural, etc). It should be noticed that CONAMA always is represented in COREMA (CONAMA 2007).

### ***3.5 Universidad Austral de Chile (UACH)***

UACH was grounded 1954 in Valdivia and it is one of the five most important universities in Chile (UACH 2007). After the environmental disaster in Carlos Anwandter Sanctuary was discovered, the university was contacted by CONAMA and performed a big study (Final Report 2005) under the leadership of Eduardo Jaramillo (Eduardo Jaramillo *et al.* 2007). CONAMA use the document Final Report (2005) as a decision basis in questions concerning the Sanctuary and CELCO-Arauco (oral comm. Enrique Suarez, CONAMA 2007-10-23). The university's standpoint in the Sanctuary case is divided and no common opinion concerning contaminating compound, the mill's involvement, etc and exists.

### ***3.6 Mehuin Ocean Defense Committee***

The organization Mehuin Ocean Defense Committee consists of fishermen from the settlement Mehuin and Mapuche Lafquenchés Indians in the regions VIII, IX and X. Their objective is to prevent the company from locating the discharge pipe in Mehuin. They have actively chased the company away and prevented them from collecting the samples which is necessary for a decision to be made. Other objectives are to spread information and create national and international opinion against CELCO-Arauco (Mehuín 2007).

They are very critical to the Chilean environmental law, because the law promotes companies instead of protecting citizens, health and environment. Mehuín is located near the sea and the settlement of fishermen who runs small-scale fisheries. The village has 1500 inhabitants and about 350 registered fishermen (oral comm. Eliab Viguera 2007-10-23). Every year, 20 000 tourists visit the village aiming to enjoying the beaches and eat shellfish (Mehuín 2007).

Mehuín Ocean Defense Committee was developed from Mehuín Defense Committee. It was formed in June 1996, when CELCO-Arauco first announced the plans of discharge into the sea near Mehuín. In the end of 1998, when the committee won the battle against the company and CONAMA/COREMA decided to locate the discharging point in Cruces River instead, a calm period for the organization begun. In May 2005, when the problems in the Sanctuary were discovered and the discussion concerning Mehuín as a location for the discharging point was brought up again, the organization woke up and changed the name to the current one. The character of the battles changed and became more violent. The committee has dispossessed the company several times and refuses communicate or negotiate with the company (Mehuín 2007).



## Appendix 4: Results

Tables over identified factors and their node states.

**Table 25 Short term nodes in the Bayesian network.**

<b>Factor - short term</b>	<b>Node states</b>	<b>Def RoL</b>	<b>Def S</b>	<b>Category</b>
Employment opportunities	Good Bad			MO
Concentration toxicant	Very high High Intermediate Low Very low			IF
Fishing	Yes – No			IF
Excursion	Yes – No			IF
Water sports	Yes – No			IF
Fish supply sea	Good – Bad			IF
Biodiversity	Yes – No			IF
Beach activities	Yes – No			IF
Shellfish	Yes – No			IF
Recreation	Yes No	> 50% < 50%	> 50% < 50%	MO
Tourism	Good Bad	1120-1600 0-1120	14000-20000 0-14000	IF
Production, CELCO	Increased Unchanged	425-550 0-425		IF
Decision CONAMA	Yes – No			IF
Public concern	Increased Unchanged			MO
Discharging point	Cruces River San Pedro River Mehuín			I
Cleaner effluents	Yes – No			IF
Perception cleaner effluent	Yes – No			IF
Process improvement	Yes – No			I
Effluent improvement	Yes – No			I
Pipe length	Long – Short			I

Evaluation of alternative discharging points from Valdivia Cellulose Plant by using Bayesian Belief Network System for environmental risk management

**Table 26** Long term nodes in the Bayesian network.

<b>Factor - long term</b>	<b>Node states</b>	<b>Def Rivers</b>	<b>Def Sea</b>	<b>Category</b>
Employment opportunities	Good – Bad			MO
Health	Unchanged Bad			MO
Concentration toxicant	Very high High Intermediate Low Very low			IF
Fishing	Yes – No			IF
Excursion	Yes – No			IF
Water sports	Yes – No			IF
Fish supply sea	Good – Bad			IF
Natural as usual	Yes – No			IF
Beach activities	Yes – No			IF
Shellfish	Yes – No			IF
Contamination fish	Yes – No			IF
Drinking water	Yes – No			IF
Recreation	Yes – No			MO
Tourism	Good – Bad			IF
Expansion, CELCO	Yes – No			IF
Culture of Mehuin	Stable Unstable			MO
Decision CONAMA	Yes – No			IF
Public concern	Increased Unchanged			MO
Discharging point	Cruces River San Pedro River Mehuin			I
Cleaner effluents	Yes – No			IF
Process improvement	Yes – No			I
Effluent improvement	Yes – No			I
Pipe length	Long – Short			I

## Appendix 5 - Interview results

In this section, the interview result is presented. All stakeholder groups participated in two meetings except of CONAMA, who did not have opportunity to take part in the second meeting. It is important to notice that this section aims to illustrate the opinions of the respondents.

### 5.1 CELCO-Arauco

#### **Interview 1: 2007-10-17 Pablo Baraña, Environmental engineer Miguel Osses, Environmental manager**

As an introduction, the respondents described the history behind the conflict. As the most interesting discharging points, Pablo Baraña and Miguel Osses pointed out the fishermen settlement Mehuin and San Pedro River (see figure 1), which were chosen to be the discharging points evaluated in this study.

CELCO-Arauco's main short term objective is to increase the production from 80 % (420 000 tons paper pulp/year) to full production (550 000 tons paper pulp/year) and in a longer perspective, expand the mill by redesigning it. To achieve this, CELCO-Arauco is dependent on permissions from CONAMA. According to Pablo Baraña and Miguel Osses, CONAMA base their decisions more on the public opinions than on technical facts, which make CELCO-Arauco dependent on the beliefs of the inhabitants of Valdivia. To decrease the pressure from the public opposition groups, CELCO-Arauco have to prove that they have not contaminated the Carlos Andwander Sanctuary. Without moving the discharging point, it will be hard for CELCO-Arauco to produce such evidences. Furthermore, CONAMA have made clear that they will not give CELCO-Arauco permission increasing the production if the discharging point is not moved.

CELCO-Arauco claim that they are completely innocent of the ecological reactions in the Sanctuary and they stress that there are missing links between results and conclusions in the Final Report made by UACH, which is used by CONAMA as a decision base. The company has followed the Chilean law and has not exceeded the effluent limitations. Many studies have been performed of different instances to prove the waste water does not inhibit the growth of Luchecillo (*Egeria densa*), but since the company has to pay for the studies the results are not accepted by the public groups opposing CELCO. Since the effluents have not impacted the Sanctuary, it would not have effects on other ecosystems. According to CELCO-Arauco, the effects of a change of location will not be ecological, but social. Further, the magnitude in the political pressure will not change, but it will be different. The respondents see Mehuin as the most suitable discharging point. The political pressure would probably be large during the first years but in a long term it will decrease. Since Valdivia city takes its drinking water from San Pedro River, this discharging point would concern more people and also increase the public pressure.

The respondents point out that the majority of the Valdivian people are not against the mill. The resistance is due to small strong groups, sometimes financed by international organizations, according to the respondents. The groups spread propaganda and affect the governmental decision making. Other important factor for the decision is the political influences, which is turning more and more to the left. This affects the newspapers which in its turn affect the public opinion.

Concerning effluent treatments and process redesigning, the company pointed out that an alternative to the third waste water treatment is under examination. The plan is to exchange the third step to using membranes instead, aiming to decrease losses of aluminum to the watercourse. They are not positive to change the process from an Elementary Chlorine Free process to a Total Chlorine Free process, since the benefits of TCF is not exceeding its drawbacks. Other interventions are continuing the communication with the public.

### **Second interview 2007-11-19 Angelo Romano, Economist and CELCO-Arauco social expert**

Since Angelo Romano insisted that the effluence would not contribute to ecological effects in any of the ecosystems, the questions and rankings concerning ecology was left out. Therefore, the interview focused on social questions and that was the reason for why CELCO-Arauco's representative was exchanged to a social expert.

Concerning the public's perception of cleaner effluents, Angelo Romano did not have much to say concerning how the public would react on different process and effluent measures. On the other hand, he thought the public perception of cleaner effluents had an important role in the public concern. The scenarios were ranked and he thought that probability for a worsened public situation in Cruces River was about 50 %. He saw San Pedro as the worst alternative from the public's point of view. He also thought that the situation in Mehuin would be hardest in the beginning and the best public alternative in a long term of time. All rankings are found in table 10 and 15.

Angelo Romano appoints CELCO-Arauco's wishes to go up to 100 % production. He was sure that the possibility for CELCO-Arauco getting permissions without changing discharging point was equal to zero. The probability was thought to be a little bit higher for San Pedro River and almost 100 % for Mehuin.

According to Angelo Romano, the relationship between CELCO-Arauco's production and job opportunities is linear. A 20 % increase in the production would lead to a 20 % increase in job opportunities. Angelo Romano was also positive to the future of the local tourism sector. He thinks an increase of 100 % is possible in a longer period of time and he points out the importance of both a touristic and an industrial development for the economic situation. Since he does not think the effluents would have any effect he is not worried about the culture of Mehuin or the recreation of the Valdivian citizen.

## ***5.2 Action for the Swans (APC)***

### **Interview1: 2007-10-19 Claudia Sepúlveda**

The objectives of the organization are to recover the Carlos Anwandter Sanctuary and preventing the same disaster from occurring in other ecosystems. APC was convinced that CELCO-Arauco is guilty of the environmental disaster in the Sanctuary and to achieve their objectives APC wants the factory to close. If that is not possible CELCO-Arauco has to be forced to follow laws and regulations, which they do not, according to APC. APC will never give their permission to move discharging point, since it is not defendable saving an ecosystem by contaminating another. Therefore, the factory has to be closed.

APC stressed that it is impossible to make decisions without having all facts. Since no studies are performed on either San Pedro River or Mehuin, a correct decision cannot be made. Further, APC claims that it is impossible to examine different effluent treatment if the compound causing the effects, are not known. According to Claudia Sepúlveda, aluminum and dioxins are the main reason for contamination. The dioxins could be eliminated by changing the process to TCF and the release of aluminum is due to the third waste water treatment step. She does not think exchanging the tertiary treatment to membranes would help, since the waste will be released into the air instead of to the watercourse.

Since the mill is of national economical importance, the government will always defend CELCO-Arauco and turn a blind eye to the environmental law. If CELCO-Arauco gets permission to release their effluents in Mehuin, there will be nothing preventing the company from further expanding. On the other hand, APC claims that the biggest loss is not the ecological one, but the social one. By offering money to affected people, CELCO-Arauco has broken up several organizations and groups, for example in Mehuin.

### **Second meeting 2007-11-20 Claudia Sepúlveda**

Claudia Sepúlveda was very critical to the installation of membranes and the artificial wetland, since the measures are installed without knowing the reason for contamination. All improvements are good but the most important is to identify the problem. Claudia Sepúlveda does not think it would change the attitude to the mill of the general public. She thinks the some of the citizens would accept it, some of them not. In the long term perspective the public concern depends on the short term output. If it becomes clear that the ecosystems are not affected by the effluents, the public and the organizations may change their minds. Claudia Sepúlveda remarks that she thinks the probability for no effect on the ecosystems in case of discharge is very low. According to Claudia Sepúlveda, the public concern in Mehuin is different than in Valdivia. If the discharging point is moved to Mehuin, there is a great risk for people getting hurt in riots between advocates and opponents of CELCO.

About 300 people are working in the tourism sector and in a longer perspective it could increase with about 100 %. An increase in CELCO-Arauco's production would not lead to more job opportunities. Concerning job opportunities in Mehuin, Claudia Sepúlveda thinks the fishery is of greater importance than the tourist business and a longer term increase of 50 % is probable. She is sure that the fishery and the tourism are independent of each other but the culture and spirit of Mehuin is all depending on the fishery.

The probability for a production increase is very high if the discharging point is moved to Mehuin and it is also very probable that the company gets permission to redesign the mill in a longer term of time. The probability for a positive decision for CELCO-Arauco is low in San Pedro River and minimal if the effluents stay in Cruces River.

The most important factor, according to Claudia Sepúlveda, is that CONAMA makes informed decisions. They are not educated in these types of questions and should consult people with good knowledge in the case, according to CS. There are a lot of people who are informed about the case and could be a good source of information for CONAMA, but CONAMA does not listen, which is a problem.

### **5.3 San Pedro River Defense Committee**

#### **First interview 2007-10-22 Roberto Salidas**

The respondent represented both the movement San Pedro River Defense Committee and the tourist company Mi Pueblito Viajes. Defensa de Rio San Pedro's main objective is to defend the river from mechanical and biological threats and to keep it as clean as it is today. The company's objectives are to develop as a company by growing and build up new tourist attractions. Mi Pueblito Viajes takes tourists for rafting, kayaking, excursion and fishing in San Pedro River. Before the contamination of Cruces River, their main activity was boat tours to the Carlos Anwandter Sanctuary. When the bird life disappeared, they were forced to change business direction. Before this happened, 300 tourists visited Cruces River per year, last year only three tourists asked for the same tour.

In the future the company wants to develop fly fishing and is planning to build a lodge near the watercourse. Roberto Salidas are sure that the tourist industry contributes with a lot more jobs per invested Chilean peso than the paper mill. If the effluents are installed in San Pedro River, Roberto Salidas is sure that the same disaster will occur as in Cruces River. Everything would die from the discharging point to the sea and the tourist company would not have anything to offer the tourists, because there are no other watercourses to move to.

According to Roberto Salidas, dioxins from the bleaching process are the main reason for contamination. Therefore, he is worried about long term effects such as mutations and cancer in both animals and humans. Further, he states that the economic effects are important but the most important is to preserve the nature to future generations. You can always get a new job but never restore the nature.

#### **Second interview 2007-11-21 Jorge Muller**

Today, the most important tourist attraction is kayaking and rafting on San Pedro River, according to Jorge Muller. This activity is very insensitive to toxicants. As long as the nature looks more or less as it did before, the tourists will come and visit. A minor income comes from the excursions, which is very sensitive to the discharges. If birds and wildlife would disappear, it would not be possible to continue the tours. The smallest activity was the fishery, but Mi Pueblito Viajes wants to develop that field. The fishery is also very sensitive to the effluents.

Jorge Muller thinks the public concern would increase the most if the point would be moved to Mehuin, second worst would be San Pedro River and the best Cruces River. Jorge Muller appoints that the most important for CELCO-Arauco improving the quality of the effluents and this is also the most important thing to do to decrease the public concern.

### **5.4 CONAMA**

#### **2007-10-23 Enrique Suarez**

CONAMA is directed by the Chilean environmental legislation and the president. As a decision base, data is required and the work is dependent on its availability. CONAMA is a governmental environmental organization and points out the importance of a healthy environment. It would for example lead to improved public health and more job opportunities.

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According to CONAMA, all alternative discharging points have drawbacks. In the Sanctuary, the freshwater meets the saltwater from the sea and the contaminating compounds are accumulated. Despite that, Cruces River is seen as the most suitable discharge point right now, because lack of knowledge about how the other ecosystems would react on the effluents. Environmental impact assessments for the other locations are required. The biggest drawback of San Pedro River is according to CONAMA that Valdivia city takes 20 % of its drinking water from the river. The benefit is that the river water goes directly to the sea and the impact should therefore not be the same as in Cruces River. In Mehuin, the social problems are of most concern. Since many other companies are discharging into the sea, some predictions can be made to see how the ecosystem would react. Henrique Suarez thinks that the sea probably is the best discharging point in an ecological point of view but the experience of other places is not enough for a decision base and an environmental impact assessment is needed.

Henrique Suarez points out that the reason for the collapsed ecosystem is not known. Possible contaminants are iron, sulfate, aluminum, but could also be some unknown factor. According to Henrique Suarez, the most important intervention is collecting data. Further, Henrique Suarez believes the most unproductive period of the Sanctuary was reached some years ago, and conditions have improved. It is possible that the ecosystem will recover independent of the effluents; if CELCO-Arauco continues discharging into Cruces River the recovery will maybe take about ten years, compared to three years without.

According to Henrique Suarez, CELCO-Arauco is investigating the possibilities and the benefits of installing membranes instead to the third waste water treatment. The membranes will remove some of the liquid effluent but the emissions to the air will increase. If the assessment comes out positively, the environmental impact will decrease. Also, the possibility constructing an artificial wetland for biological treatment of the effluent is under examination. The idea is to let the waste water pass through the artificial wetland before entering the watercourse. The Brazilian company Centro Nacional de Tecnologias Limpas (CNTL) is working with the case. Enrique Suarez remarks that a better effluent is essential for ongoing production.

If Cruces River is kept as discharging point and effluent improvements are implemented the recovery would in the best case speed up. According to CONAMA, the worst case for Cruces River has already occurred. In Mehuin, Henrique Suarez thinks a long pipe would help preventing contamination. The biggest problem in Mehuin is the social factors, and it is also hard to predict. The worst case would be something like a civil war or that people got killed. Also, Henrique Suarez states the possibility that the fishery will be affected and the fishermen will have to move. If the discharge reach San Pedro River, its effects would probably not be as bad as in Cruces River, because San Pedro River goes directly to the sea. On the other hand, the Valdivian people are environmental friendly and have strong opinions, why San Pedro River is an unsuitable location because of the drinking water uptake. In best case, San Pedro River would just suffer from minor contamination.

## ***5.5 Universidad Austral de Chile (UACH)***

**First interview 2007-10-23 Eduardo Jaramillo, Pablo Villarroel Venturini**

The watercourses were compared to each other with and without adding the effluents: In Cruces River, the best alternative, according to UACH, would be to improve the effluents by

leading the discharge through an artificial wetland and change the process to TCF. Also, decrease the use of aluminum chloride and re-circulate the process water would contribute to cleaner effluents. Today, the waste water is not clean enough for discharging in *any* watercourse. UACH thinks it would be very hard for the Sanctuary to recover if the effluent is of the same quality as it is today. In an ecological point of view, UACH considers Cruces River to be the worst alternative, since it passes through the sensitive wetland. UACH do not think the membrane system is a definitive solution for the waste water treatment. If no effluents at all would be discharged into the Sanctuary it would probably recover in a few years.

Because of the city's water uptake UACH sees San Pedro River as a very bad alternative. On the other hand, the dilution is high which leads to a decreased concentration of the toxicant. Today the river is clean, but the government is planning to construct a hydroelectric power station upstream the city, which would have big effects on the ecosystem. In case of a discharge, the dam would increase the accumulation rate of the compound and similar effects to the ones in Cruces River would be achieved.

If Mehuin was chosen as a discharging point, the effects could be minimized if the interventions mentioned above were implemented and a long pipe (over 2000 meters) would be installed. The worst alternative would be a short pipe and no improvements in the effluent treatment, which could lead to a less productive fishery and maybe the end for the fishermen community. If the discharging point would *not* be located in Mehuin, UACH thinks that the fishery is threatened anyway due to other industrial exploitations.

According to UACH, the compounds causing the effects are AOX, sulfates, aluminum and chlorates. Sulfates and chlorates are pesticides and AOX contains dioxins, which are toxic and bio-accumulating. For humans, the long term effects of dioxins and heavy metals are the most worrying in this case.

UACH sees the Final Report by UACH(2005) as the best available study that exists today. UACH points out the difficulties finding independent research teams. On previous occasions, the majority of the big universities in Chile have worked with the company. This decreases the public's faith for universities and their studies and the public would have difficulties accepting the results.

## **Interview 2: 2007-11-20 and 2007-11-21 Eduardo Jaramillo**

Concerning the most important parameters for the toxic concentration in the rivers, Eduardo Jaramillo thought that the discharging point was the most important, due to the water flow. It was followed by the parameter cleaner effluents and an increase in the production had the least impact, according to Eduardo Jaramillo. If the discharging point would be moved to the sea, the pipe length was thought to be most important and an increased production was neglected due to the high dilution in the sea. In a longer term, he thought that the production rate would impact the concentration. See section 4.2.2.1 and 4.3.2.1 for detailed information.

Since nobody knows which compound that affected the Sanctuary and maybe would have impact in the other watercourses, it is hard to predict how the ecosystem functions would react on the concentration. Despite that, Jaramillo concludes that all ecosystem functions have



a negative relation to the toxicant concentration. An increase in concentration contributes with lower ecosystem functions. Fish supply, shellfish and excursions are all very sensitive to pollution. The toxic effects on human health are long term effects and it is very hard to predict its magnitude.

Concerning cleaner effluents, the most important measure is the effluent treatment since the process change is related to big drawbacks. The best result would of course be achieved if both measures would be installed. Eduardo Jaramillo thinks that the measures of the effluents are effective enough to discharge into the water courses with minor effects on the ecosystem.

If the discharging point would be moved to Mehuin, Eduardo Jaramillo thinks the possibility for CELCO-Arauco increasing the production would be very high. If the point would be moved to San Pedro River, the possibility would be very low and zero, if it continues in Cruces River.

## ***5.6 Mehuin Ocean Defense Committee***

### **First interview 2007-10-23 Teresa Castro and Eliab Viguera**

According to Mehuin Ocean Defense Committee, lots of sites along the Chilean coast are contaminated, which has caused both ecological and cultural damage. Many Indian communities live of the ocean both economically and spiritually and many of them have been forced to move, because of lack of food. The fishermen in Mehuin will not let the same thing happen to them. CELCO-Arauco's promises concerning that the effluents would not have any effects on the ecosystem are not believed by Mehuin Ocean Defense Committee, who is referring to the ecological reactions in Carlos Anwandter Sanctuary.

The objective for Mehuin Ocean Defense Committee is to stay in Mehuin as fishermen. Further, they want to preserve the sea for their children and develop as a community. If CELCO-Arauco would install the pipe Mehuin Ocean Defense Committee are convinced that everything in the ocean would die and the fishery and the village as well. They are concerned about long term effects as mutations, cancer and feminization of species. Both the quality and quantity of the fishery would be affected in case of discharge. Their opinions are based on experience from other fishing communities.

The fishermen of Mehuin run small scale fisheries, which mean that they are bounded to certain quotas. All the 1500 inhabitants are dependent of fisheries and there are 450-500 persons registered as fishermen. There are three types of fishery practiced in Mehuin: The bigger types of fish are to be found near the shore; shellfish in the nearby Lingi River and sprats and sardines, further out in the sea. At the moment the fishermen of Mehuin do not have permission to catch sprats and sardines. Usually the catch is good during December to September but poor in October and November. The Lingi River is used by fishermen and the interaction between the seawater and freshwater is important. If the catch is good it is a benefit for the whole village, because the inhabitants spend more. Further, 20 000 tourists visit the village every year, visiting the beach and eat shellfish.

The fishermen are worried about the effects of the pollutants organic chlorides, dioxins and furans, which are released by CELCO-Arauco according to Mehuin Ocean Defense Committee. The compounds would eliminate the plankton, which will have effects on the fishery. Mehuin Ocean Defense Committee thinks the first zone affected would be the one

near the shore because of the sea currents, thereafter the pollutant will reach further out and finally the fishery in the river would be influenced. The sea would rapidly be affected because of three factors: The effluent is freshwater, the temperature of the water and “latitud de los 40” (a strong wind). This would make the pollutants move in the water quickly and would contaminate the whole shoreline in a couple of hours. The fishermen think the fishery would be affected in about tree month.

Another threat of the sea and the fishery is the forestry, which has been using illegal pesticides. The compounds has been transported to the sea though rivers and have affected the meat quality of the fish and the shell of shellfish. The fishery in Chile is badly affected of contaminates and is threatened in a long term of time. Mehuin Ocean Defense Committee thinks more powerful legislation could help preventing similar situations in the future. Today the public opinion does not have any value at all. People are interested but no one is listening, states Mehuin Ocean Defense Committee.

**Second interview 2007-11-21**  
**Gino Bavestrello**

Many tourists arrives Mehuin every year aiming to visit the beach and the shellfish restaurants. According to Gino Bavestrello there are very few restaurants and hostels, which make the beach activities to the main attraction. Gino Bavestrello is sure that the tourist business has a great potential in Mehuin. According to Gino Bavestrello, the tourism and the fishery are tightly related. Without the fishery neither tourism nor life would exist in Mehuin. Both fishery and tourism have the possibility to develop in a longer term of time. The tourism business could easily develop by making an effort in making money out of the arriving tourist. The fishery could give more money if the fish could be sold outside Mehuin.

Except of beach activities and shellfish business, the fishery is an essential ecosystem function. According to Gino Bavestrello, among these three activities the shellfish is the most sensitive, closely followed by the fishery. The beach activities are more resistant to pollution. Gino Bavestrello thinks the contamination of fish is a long term effect but could be really serious.

## Appendix 6: Definitions

In this section, definitions of risk, uncertainty and probability will be discussed.

### 6.1 Uncertainty

Mathematical models contain uncertainties in different levels: uncertainty in the choice of the model and the model itself, uncertainty in the input variables and the in interpretation of the results (Lundin 1999). All types of uncertainties will affect the final result and to be able to deal with them in a proper way, the understanding of how they are introduced is important. By categorizing the uncertainties, its sources can be identified and the best way of treating them can be found, since the choice of treatment depends on to which category the uncertainty belongs to. Lundin (1999) uses the following categorization of uncertainty, first stated by Energistyrelsen (1996):

- Resources
- Assumptions and decisions
- Mathematical models
- Input data

Lundin (1999) uses figure 54 below to show how the different types are related to each other.

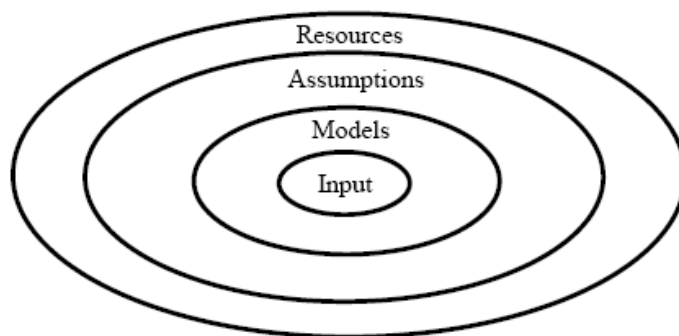


Figure 54 The relationship between different types of uncertainties (Lundin 1999).

As shown in the figure, uncertainty in resources is the most general type. Questions as time and money play an important role and can limit the range of models and the performance of the study. This type can be hard for the engineer to deal with, since the decisions related to this group are often not in the hands of the engineer.

When the resources have been allotted, the engineer herself will be contributing with uncertainties by making assumptions regarding description of the problem, limitations and choice of analysis method (Lundin 1999). These types of assumptions cannot be avoided, since a model is a simpler version of the reality. The documentation of the assumptions is of importance for the transparency in the study and the possibility for others to control how the assumptions have been made.

The uncertainty of the input data will be reflected in the final result and finding high quality input data is therefore of importance (Lundin 1999). Input data can be obtained for example by making measurements and through interviews. Sometimes it is hard to find sufficient amount of data, which makes it hard to analyze it with classic statistics. By using the Bayesian approach, expert judgments can be used to complement the observed data (Ang and Tang 1975). The Bayesian approach will be discussed later.

## 6.2 Probability

In statistics and uncertainty analysis both classic statistics and the Bayesian approach are used. Classic statistics is only based on frequencies; whereas Bayesian statistics lets subjective judgments and new information impact the results. However, the same counting rules are used in both approaches (Kaplan and Garrick 1981, Ang and Tang 1975).

In Bayesian statistics, probable values for a stochastic variable are estimated by collecting new information or taking expert opinions into account. This information is then used to adjust the hypothesis. The values that best agreeing with the true value will get an increased probability. In other words, the probability distribution is dislocated towards the observed value. If sufficient new information is added to the Bayesian calculations, the Bayesian estimations will give the same result as the classic. Therefore, it is important that the “real” value is included among the hypothesis are assumed (Ang & Tang 1975). The strength in Bayes statistics is that predictions can be made with a poor base of data, which is not possible in the classical approach.

To describe a variable, which can adopt different values, a stochastic variable is used and it can adopt both discrete and continuous values. If a stochastic variable can embrace a finite or enumerated infinite numbers it is defined as discrete. To describe a discrete stochastic variable a probability function is used (Johansson 2000).

If  $\theta$  is a stochastic variable with distribution  $p(\theta)$  and  $p(\theta)$  do not includes the data set  $Y = (Y_1, \dots, Y_n)$ , the distribution  $p(\theta)$  is the priori distribution and the data set  $Y$  represents the uncertainty of  $\theta$  before  $Y$  arrives. When the outcome of  $Y$  is known, the uncertainty is now represented of the distribution  $p(\theta|Y)$  and is the conditionally probability of  $\theta$  when  $Y$  are known. This distribution is called the posteriori distribution. By using Bayes theorem,  $p(\theta)$  can be updated to  $p(\theta|Y)$  and  $p(Y|\theta)$  is called the likelihood function (Draper 2002). Bayes theorem is illustrated in equation 15.

Bayes Theorem: 
$$p(\theta|Y) = \frac{p(\theta) \cdot p(Y|\theta)}{p(Y)} \quad (15)$$

## 6.3 Risk

All kinds of situations are associated with risks and it is impossible to avoid them. Rather, the aim is to choose between the risks. To be able to do so in a proper way, the term must be clearly defined (Kaplan and Garrick 1981). Today, a common definition of the term risk does not exist but it has different meanings dependent on the context in which it is used. Some people see risk as a social construction whereas others see it as a combination of objective

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probabilities and losses in different constellations (Renn 1998). Mattsson (2000) states four different meanings of risk:

1. A threat or a danger
2. A probability
3. A combination of probability and consequence
4. A distribution

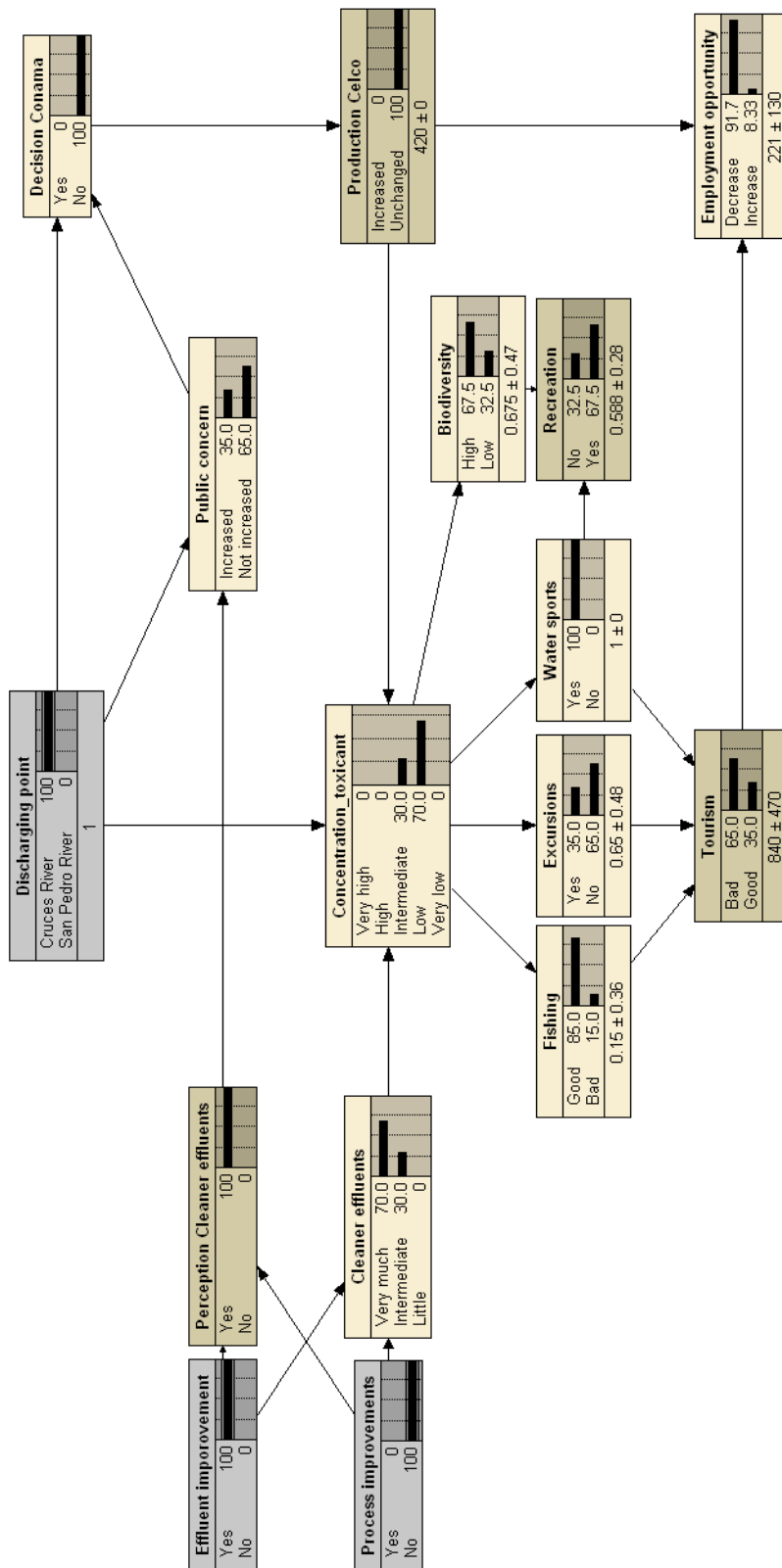
Number three could be seen as the traditional definition of risk and reminds of the quantitative definition declared by Kaplan and Garrick (1981). In order to give the risk a quantitative value, they stated three key questions for risk analysis:

1. What can happen (i.e. what can go wrong)?
2. How likely is it that that will happen?
3. If it does happen, what are the consequences?

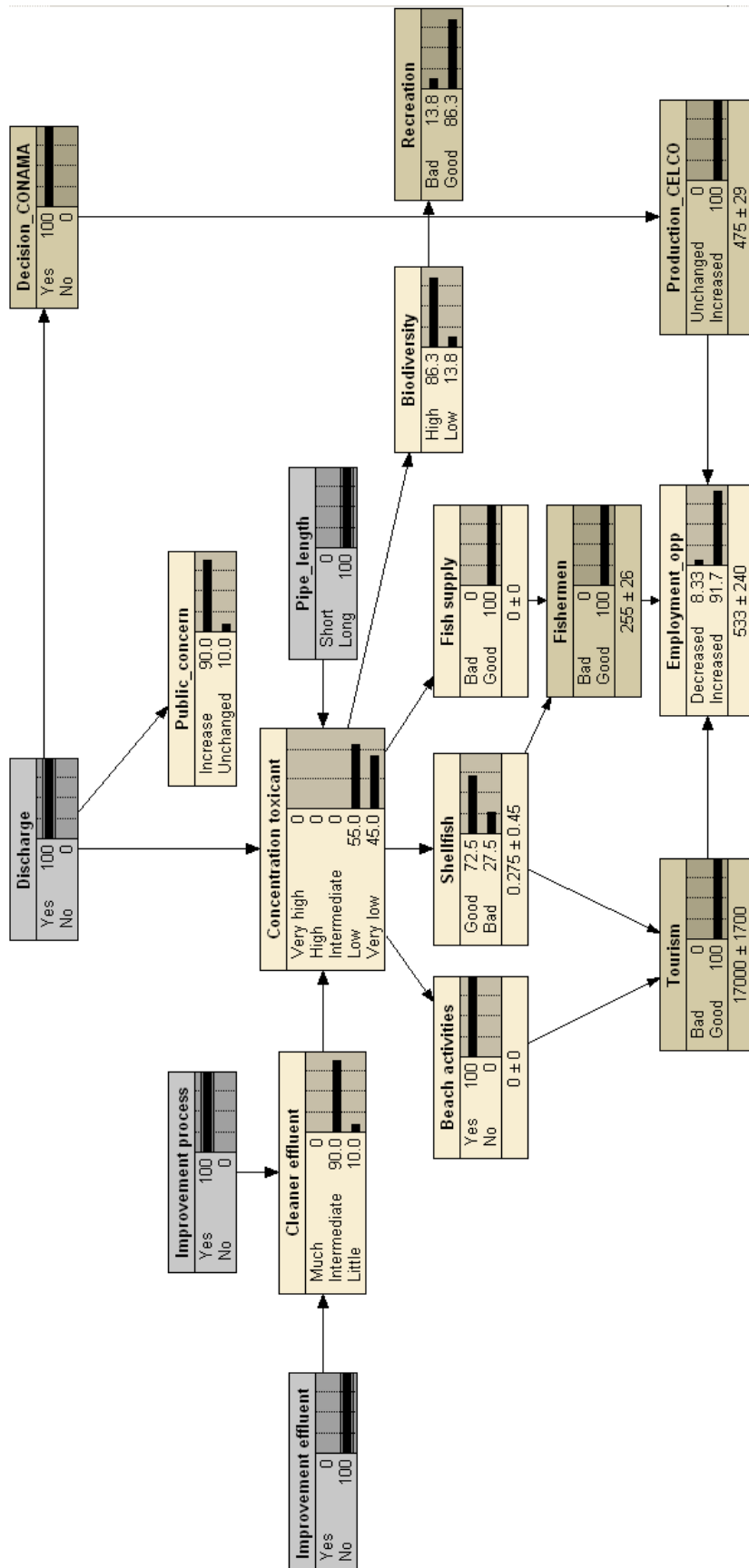
$$R = \{(s_i, p_i, x_i)\}, i = 1, 2, \dots, N \quad (16)$$

The first point refers to the scenario,  $s_i$ , the second to the probability of the scenario,  $p_i$  and the third to the consequence of the scenario,  $x_i$ . Risk ( $R$ ) is then defined as the triplet showed in equation 15. Kaplan & Garrick's (1981) definition of risk will be used in this report.

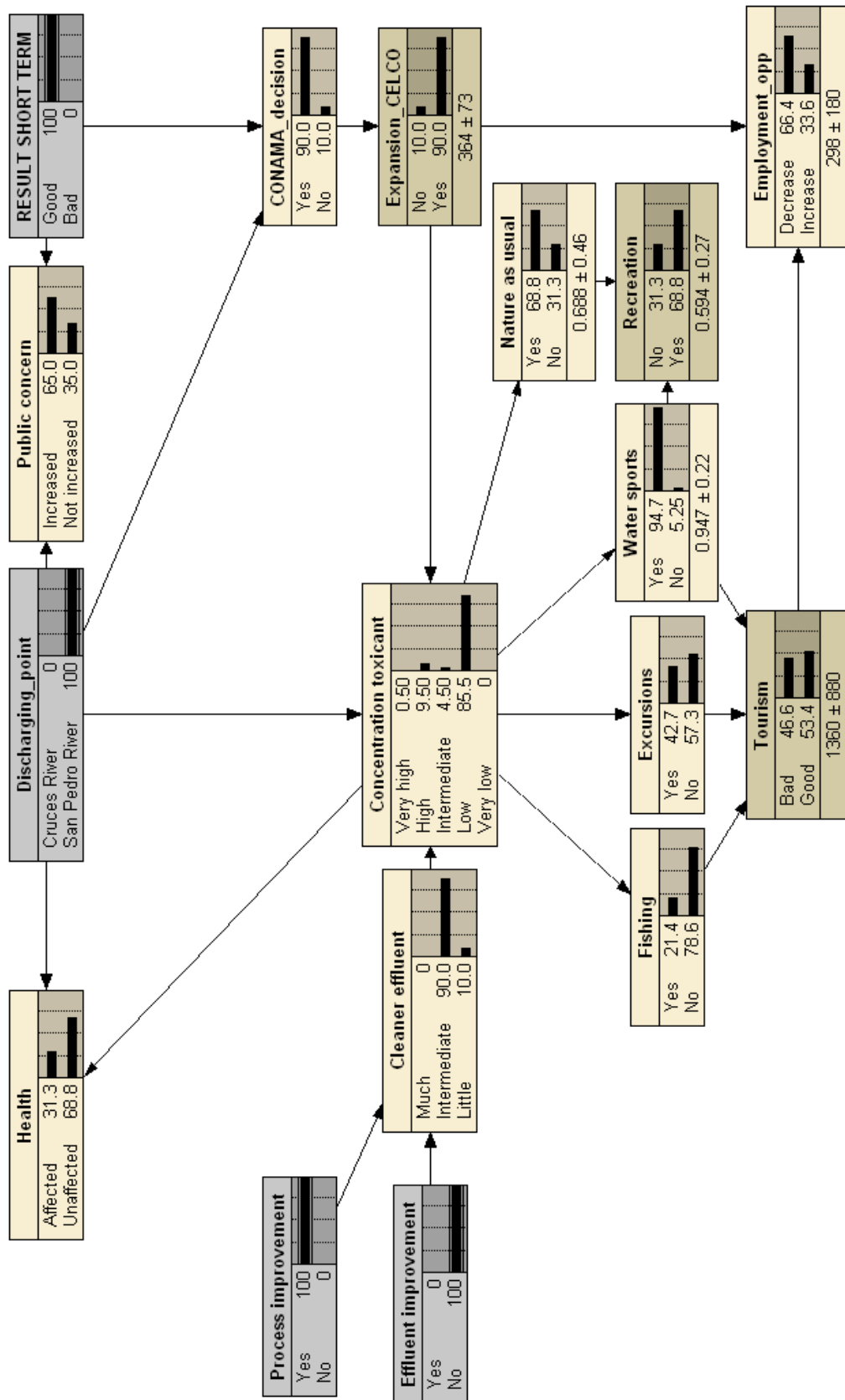
## Appendix 7: Short term Bayesian network for Cruces and San Pedro Rivers



## Appendix 8: Short term Bayesian network for Mehuin



## Appendix 9: Long term Bayesian network for Cruces and San Pedro Rivers





## Appendix 10: Long term Bayesian network for Mehuin

