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A COMPARTMENT MODEL FOR ^{90}SR CONTAMINATION IN A WETLAND AT THE CHALK RIVER LABORATORIES

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ABSTRACT

Radioactive wastes originating from Canada's nuclear research and development program have been managed at the Atomic Energy of Canada Limited (AECL) Chalk River Laboratories (CRL) since 1946. In 1953 an area called Waste Management Area "B" (WMA B) was developed to contain low and intermediate level solid waste (LLW and ILW respectively). Initially, all of the wastes were buried in unlined sand trenches or in asphalt lined trenches. These early trenches have been releasing strontium-90 (^{90}Sr) to groundwater since 1954, resulting in an underground contaminant plume. A treatment system was constructed in 1994 and as a result the plume is being intercepted and treated for removal of ^{90}Sr. Prior to the establishment of the treatment system the plume extended south and discharged into a watercourse called "Spring B", then into a wetland area called "West Swamp". Routine monitoring of Spring B and the West Swamp outflows for ^{90}Sr has been conducted since the 1960s.

A compartment model of the West Swamp was developed and validated against monitoring data for Spring B. The purpose of developing the model was to determine if a standard compartment model could describe ^{90}Sr dynamics in a wetland to support environmental decision making. The model employed mass balance calculations to describe the movement/distribution of ^{90}Sr between the primary system compartments: water/peat, sediment, vegetation and litter. This paper describes how the compartment model was developed and validated. The model can be used as a tool to evaluate remediation alternatives and to provide input to CRL site decommissioning plans.

1 INTRODUCTION

Radioactive wastes originating from Canada's nuclear research and development program have been managed at the Atomic Energy of Canada Limited (AECL) Chalk River Laboratories (CRL) since 1946. Facilities to store the early wastes were sited in the sandy uplands of the Perch Lake watershed, approximately 2 kilometres from the Ottawa River. The waste management facilities were located in this area because all groundwater from this basin, with the exception of a small intermittent flow to Toussaint Lake, drains to Perch Lake and then to the Ottawa River via Perch Creek. Thus, any leachate plumes emanating from the facilities would be attenuated and diluted, and could, if necessary, be collected, monitored and processed if the levels of radioactivity posed a threat downstream of the plant (AECL, 1997).

In 1953 an area called Waste Management Area "B" (WMA B) was developed to contain low and intermediate level solid waste (LLW and ILW respectively). Initially, all of the wastes were buried in unlined sand trenches or in asphalt lined trenches. These early trenches have been releasing strontium-90 (^{90}Sr) to the groundwater since 1954, resulting in an underground contaminant plume. The plume extends south and discharges into a watercourse called "Spring B", then into a wetland area called "West Swamp" (see **Figure 1**). In 1957 routine monitoring of Spring B began and in 1960 the monitoring program was expanded to include the West Swamp outflows to Perch Lake. By 1973, all of the inflows and outflows of the West Swamp were being monitored. In 1993 a treatment facility was commissioned to intercept and remove ^{90}Sr from the groundwater discharge area at Spring B. Currently the facility removes over 99% of the ^{90}Sr from the plume (AECL, 1999).

AECL is developing decommissioning plans for its waste management areas. These plans will determine the sequence and scope of remedial activities over a 400 year period. This is assumed to comprise a site operational control period of 100 years (i.e. period of time over which ongoing operations will be supported), and an administrative control period of an additional 300 years during which time site access will be controlled and facilities will be monitored. The decommissioning plans for WMA B and the surrounding area will include the management of contamination in the West Swamp. The decommissioning plans will include an analysis of the human, environmental and economic benefits, risks and costs associated with various strategies and schedules for managing contamination in the wetland. To accomplish this analysis, a reliable means to predict the ^{90}Sr releases from the West Swamp to Perch Lake over a prolonged period of time is required.

Mass balance compartment models have been widely used to simulate contaminant transport in the natural environment (Diamond et al., 1994, 1996; Doyle, 2002; Soetaert and Herman 1995a, b; Stephenson et al. 1995). Mass balance wetland models have been used previously within the Nuclear Fuel Waste Management Program (Reid et al. 1996, Sheppard et al. 1996). Jacques

Whitford has developed mass balance compartment models to evaluate contaminant fluxes in support of remedial options evaluation at Muggah Creek (Sydney Tar Ponds), Sydney, Nova Scotia (JDAC 2003) and in St. John's Harbour (Newfoundland Dockyard), Newfoundland (Jacques Whitford 2004).

In 2002 a research project was initiated as part of an M.Sc program to develop a compartment model of ^{90}Sr transport and distribution in wetlands in support of decommissioning plans for the West Swamp and other areas of the CRL site (Doyle, 2002). This paper describes how the compartment model was developed and validated. The model can be used as a tool to evaluate remediation alternatives and to provide input to CRL site decommissioning plans.

2 SITE DESCRIPTION

Radioactive wastes were buried in 39 unlined sand trenches in WMA B between 1953 and 1963. The trenches were excavated so that the bottoms would be 1 m above the normal groundwater table. The groundwater contamination plume emanating from the trenches is comprised almost entirely of ^{90}Sr, and contains no appreciable levels of non-radiological contaminants such as heavy metals or organic compounds. The plume runs through a sandy matrix overlaying a basal aquitard of glacial till. The single contaminant nature of the plume is due to a chromatographic effect within the attenuation region surrounding the trenches and reflects the relatively high solubility and mobility of ^{90}Sr in aqueous systems. Other radionuclides are far less mobile than strontium and are retained in the immediate vicinity of the trenches.

The groundwater plume discharges to a wetland via "Spring B". The plume is intercepted at this point, and is treated to remove ^{90}Sr before the treated water is discharged to West Swamp. The maximum measured concentration of ^{90}Sr in the aquifer solids affected by the groundwater plume is 6,000 Bq g^{-1}. The ^{90}Sr plume migrates in pulses and tends to hug the basal aquitard. The pulsing phenomenon is possibly due to the periodic failure of containers within the sand trenches or increased periods of leaching due to seasonal and year-to-year variation in groundwater levels or precipitation.

The local discharge area for the groundwater is at Spring B, where the ^{90}Sr contaminated groundwater forms a surface contamination plume in the West Swamp. This surface contamination is shown in **Figure 2** and represents the scope of the research study. The surface contamination plume is narrow (300 to 400 m wide) and is about 1,500m long. The highest concentrations of ^{90}Sr are in the centre portion of the plume nearest Spring B. The plume becomes less radioactive as it extends laterally and lengthwise towards Inlet 1 and Perch Lake. Contamination levels range by over an order of magnitude between the higher activity areas near Spring B and the distal and lateral portions of the plume. It is also observed that there are no significant sources of contamination entering the West Swamp area other than via Spring B.

The West Swamp area consists of two main plant communities: a tall shrub and hardwood swamp (hardwood swamp) located near Spring B, and a narrow-leaved emergent marsh (cattail marsh) comprising the main body of West Swamp. The hardwood swamp is 0.5 ha and the biomass is dominated by black ash (*Fraxinus nigra*), followed by yellow birch (*Betula alleganiesis*), balsam fir (*Abies balsamea*), American elm (*Ulmus americicana*) and white spruce (*Picea glauca*). The cattail marsh is dominated by *Typha latifolia* and to a lesser degree Canada bluejoint grass (*Calamagrostis canadensis*). The cattail cover was estimated at between 30 and 80% and dead cattail stems form a continuous mat under the living stems. Canada bluejoint grows between the cattails and sometimes forms up to 70% of the ground cover.

3 METHODS

3.1 Conceptual Model Development

In this model, the bulk of the ^{90}Sr in the biomass is assumed to reside within the substantive living portions, such as tree trunks and roots, and the roots and stems of living emergent herbaceous vegetation. Recycling of ^{90}Sr back to the wetland is conceptualized as being due solely to litter loss and decomposition. Direct redistribution of ^{90}Sr to the environment from the biomass (i.e. not via the litter) is assumed to be insignificant except under unusual conditions (e.g., forest fire). The rate at which ^{90}Sr is recycled to the swamp, via the litter layer will depend upon the type of vegetation present.

The litter component of the wetland represents an intermediate stock of ^{90}Sr, existing between the living vegetative biomass and the wetland (water/sediment) compartments. The litter is differentiated from the wetland organic matter in that the ^{90}Sr is incorporated in the non-living but still identifiable plant tissue, as opposed to being adsorbed to undifferentiated organic matter ("muck"). Strontium is not released to the wetland water or sediment until the litter decomposes.

Below the root zone (i.e., the saturated top 20 cm of the wetland) lies the sediment layer. It is generally comprised of more mineral soil components than the wetland layer, and has a higher ion exchange capacity for ^{90}Sr (Belli and Tikhomirov, 1996). This layer is assumed to be a sink for ^{90}Sr in the wetland system.

The biomass in the CRL study area is comprised of two vegetation types:

- a treed riparian swamp, and
- a cattail and sedge marsh land.

The cattail marsh is the dominant vegetation from an overall model perspective and both vegetation types could conceivably be modelled as one compartment. However, the uptake, internal distribution and the rate of cycling of ^{90}Sr will likely differ between the two vegetation types. These differences could be important considerations when using the model to understand localized environmental effects or in quantifying source terms for safety assessments. Therefore, the model accounts for both vegetative types by dividing the biomass compartment into riparian and marsh sub-compartments. The conceptual model for the West Swamp wetland is shown in **Figure 3**.

3.2 Mass Transfer Equations and Transfer Coefficients

The transport and distribution of ^{90}Sr through the system can be described as a series of first order linear equations (Alexakhin et al., 1994; Prohorov and Ginzburg, 1972; Schell et al., 1996) that take the general form of:

$$dN_{x,i} = N_{x,i-1} + \left(\sum F_{inputs} - \sum F_{outputs} - \sum F_{decay}\right) \cdot dt \qquad [3.0]$$

To complete the model, mass transfer equations were developed to describe each flux mathematically, and input parameters and transfer coefficients were selected to calculate the fluxes of ^{90}Sr from compartment to compartment. The parameters and transfer coefficients selected were developed from a combination of experimental data or field observations, and parameters obtained from the literature. The mass transfer equations, input parameters and transfer coefficients used in the West Swamp model are provided in **Appendix A**, and a full description of how they were derived can be found in Doyle (2002).

The contaminant flux model was implemented using STELLA, Version 6.2 for Windows (High Performance Systems Inc., 2000), based on the conceptual model and differential equations described in Section 3.1. The STELLA software calculates the transfers and mass of contaminant in each compartment for each pre-determined increment of time, and stores or plots the data in a “user-friendly” format.

Initial ^{90}Sr values of the compartments were assumed to be zero, representing conditions in 1957, before appreciable contamination of West Swamp had occurred. The ^{90}Sr to West Swamp from Spring B used in the model is based on monitoring data collected by AECL since 1957 (**Appendix B**). The time period (*i*) selected for this model is 1 year. Annual intervals were selected because the overall timeframes being evaluated are long (i.e. 100-400 years), incremental seasonal changes are not being considered, and short term effects requiring detailed exposure rates (e.g. human or animal dose calculations) are not being evaluated. The complete wetland model is shown diagrammatically in **Appendix A**.

3.3 Model Reliability

The ability of models to successfully make predictions has been termed “model reliability” (IAEA, 1989). Reliable models should make predictions that correlate well with observational outcomes over a wide range of environmental conditions.

Model reliability was optimized by the following means:

- verification of model integrity and correction of computational errors,
- validation of the model by comparison with independent data and subsequent calibration of the model by adjustment of model parameters.

Model verification provides assurance that the model is a proper mathematical representation of the conceptual model and that the equations are correctly encoded. Verification can be achieved by testing the model against known solutions to equations, as opposed to measured or observed data (IAEA, 1989). Alternatively, evaluating the validity of the conceptual model or model parameters requires the comparison of predicted and observed data. It is important that the data used to validate the model are independent of the data used to develop the model (Jordan et al., 1973; Håkanson, 1993) and are compared against model predictions before the model parameters are adjusted to improve the fit of the data (IAEA, 1989). This model was validated by comparing the annual flux of ^{90}Sr out of West Swamp and the total wetland inventory of ^{90}Sr to the observed values provided in **Appendix B**, unpublished data, and data obtained from field sampling.

The West Swamp model was verified in the following three ways:

- the equations and parameters used in the STELLA® software were confirmed by independent review to match the equations and parameter values developed (i.e., the code was checked);
- the sum of the model outputs confirmed that mass was not being created or destroyed; and
- the units of measure were confirmed to balance for the overall set of model equations.

The validity of the conceptual model was determined by comparing actual and predicted values for ^{90}Sr outflux from the wetland and for the ^{90}Sr inventory of West Swamp. The model predictions were plotted against observed values and the closeness of “fit” was determined by linear regression analysis. The STELLA® model was run with an initial set of parameter values and transfer coefficient values and the annual predicted output and actual values were compared. Several iterations of the model were run using different parameter values until the “best fit” between predicted and actual data was achieved. This is termed model calibration. The calibration of the West Swamp model is fully described in Doyle (2002).

The final model parameters used are summarized in **Appendix A,** and **Figures 4a to 4d** show the output predictions plotted against actual values with linear regression analysis of the ^{90}Sr flux to Perch Lake and the inventory of ^{90}Sr in the wetland. It was observed during the trial runs that changing the parameters resulted in only slight improvements in the reliability of the model. The correlations between the predicted and actual output flux of ^{90}Sr from West Swamp improved modestly from $r^{2\sim}$ 0.60 to $r^{2\sim}$ 0.61 and from $r^{2\sim}$ 0.82 to $r^{2\sim}$ 0.87 for the predicted and aggregate wetland ^{90}Sr inventory. The final model predictions were very closely correlated with the actual values for both ^{90}Sr outflux and aggregate inventory until the sharp decline in ^{90}Sr input from Spring B in 1990, after which time the model under-predicts the ^{90}Sr flux out of the wetland significantly. This may be related to the scatter in the data, possibly reflecting sampling and analysis error. Strontium levels in the marsh biomass were also observed to have dropped as well.

The residence time of a radionuclide in a soil compartment is related to the retardation factor and pore water velocity through the compartment (Kirchner, 1998). The residence time for ^{90}Sr in the wetland was calculated to be 18.8 years. This is substantially greater than the influx period, thus the wetland will act as a well-mixed compartment. The residence time is also comparable to residence times in forest ecosystems as reported by Jordan et al. (1973) and Alexakhin et al. (1994).

4 COMPARTMENT MODELS AND DECOMMISSIONING PLANNING

Given the reasonable agreement of the model predictions with the observed values, the transport and distribution of ^{90}Sr in the wetland in the future can be assessed. Specifically, the anticipated levels of ^{90}Sr in the wetland and outflux to Inlet 1 over the 100 year operational control period, after which the WMA B source term will have been remediated, can be predicted. For example, the following three scenarios could be analysed as part of developing a decommissioning strategy for the West Swamp:

- do nothing (i.e. do not treat Spring B water),
- continue the current level of intervention (i.e. treat Spring B discharge), and
- introduce a higher level of intervention (e.g. active removal of ^{90}Sr from the wetland).

The "do nothing" scenario assumes the Spring B facility is not operating and ^{90}Sr flux into West Swamp would be at a constant level approximating the Spring B ^{90}Sr levels for the last five years, say 5 GBq a^{-1}. ^{90}Sr outflux and wetland compartment inventories for this scenario are shown in **Figures 5a and 5b** (note: the Y axis units are in GBq). Strontium outflux is observed to reach a steady-state level of slightly over 3 GBq a^{-1} after approximately 75 years, well within the operational control period. Similarly, steady-state levels for inventories in ^{90}Sr in the wetland biomass and sediment compartments are likely to be reached within approximately 75 years. The model can thus be used to describe scenarios for safety assessments well into the future. For example, biomass and wetland inventories can be used as source term estimates for accident scenarios, such as the West Swamp drying out and a fire occurring in the region, after the site operational control period has elapsed.

The second scenario assumes the continuing treatment of Spring B water at current removal rates. **Figure 6a** shows the predicted outflux of ^{90}Sr to Inlet 1 and **Figure 6b** shows the predicted wetland and biomass inventory ^{90}Sr levels with ^{90}Sr influx to West Swamp from Spring B maintained at 0.1 GBq a^{-1}. The flux of ^{90}Sr out of the wetland is observed to decline gradually and reaching a steady state after approximately 75 years to 0.16 GBq a^{-1}, or less than 1.5% of the peak outflux of ^{90}Sr in 1996. This gradual release of ^{90}Sr reflects the dampening effect of the wetland cycling the ^{90}Sr through the biomass. Levels of ^{90}Sr in the biomass, litter and wetland compartments show similar gradual declines in ^{90}Sr levels. Sediment levels, although low, also increase for a period of time then begin to reduce accordingly. By comparing the predictions in **Figures 5a and 5b** with **Figures 6a and 6b** the benefit of maintaining the Spring B treatment becomes clear and quantifiable. Alternatively, the potential benefits of improving the facility operation can be assessed by incrementally reducing the influx of ^{90}Sr to Spring B in the model and the potential environmental benefit of reducing ^{90}Sr outflux can be weighed against the cost of upgrading the ^{90}Sr removal efficiency of the Spring B treatment facility.

Finally, the model could be used to assess the benefits of direct interventions. For example, cattails can be used to remove contaminants from treatment wetlands by harvesting the plant annually. The environmental benefit of an intervention (i.e. reduction in ^{90}Sr inventory) in the West Swamp can be simulated by reducing the marsh biomass to litter transfer coefficient (TCml) to a very low number, or to zero (see Figure 5.3a). In this case the marsh biomass becomes a sink with annual harvesting of the cattails, and the environmental benefit can be quantified by comparing the predicted outflux and inventory of ^{90}Sr in the wetland with and without intervention (i.e. compare **Figures 7a** curve 2, and **Figure 7b** curve 1 with **Figure 6a** curve 2 and **Figure 6b** curve 1 respectively).

The future environmental benefit of the intervention can now be quantified and compared against the operational costs associated with the harvesting of cattails and the environmental risks associated with carrying out the intervention. In this case, a steady state levels for the flux of ^{90}Sr out of the wetland, and the inventory of ^{90}Sr in the wetland, are reached after approximately 20 years, at levels comparable to the previous scenario (i.e., continuing treatment of Spring B water). This represents a reduction in the ^{90}Sr flux to Perch Creek of approximately 8 GBq. However, these benefits are achieved at the risk of disturbing sediments and increasing the actual release rate of ^{90}Sr resulting from harvesting the cattails.

5 CONCLUSIONS

A dynamic model comprised of four primary compartments, wetland (i.e. water/peat), biomass, litter and deep sediments, was developed to describe the flux of ^{90}Sr through the West Swamp. The biomass and litter compartments were divided into separate riparian and marsh components allows for the determination of future ^{90}Sr levels as input to decommissioning plans for the West Swamp and other wetlands at CRL. The residence time for ^{90}Sr in the West Swamp wetland is estimated to be 18.8 years and the minimum residence time of water in the wetland is 0.6 years; therefore, the wetland is acting as a well-mixed compartment.

The compartment model developed for the West Swamp provides a simplified but effective and sufficiently accurate means to understand the behaviour of ^{90}Sr in the wetland and the STELLA® software is a useful tool for developing the compartment model concept, optmizing model parameters and demonstrating the model's predictive capability. The model can be easily adapted to various environmental scenarios to provide quantitative information regarding the effects and potential environmental benefits of proposed remedial actions. The wetland model outputs can then be used to quantify environmental risks and/or the benefits of various direct and indirect interventions as well as describing the outcome of maintaining the *status quo*.

6 ACKNOWLEDGMENTS

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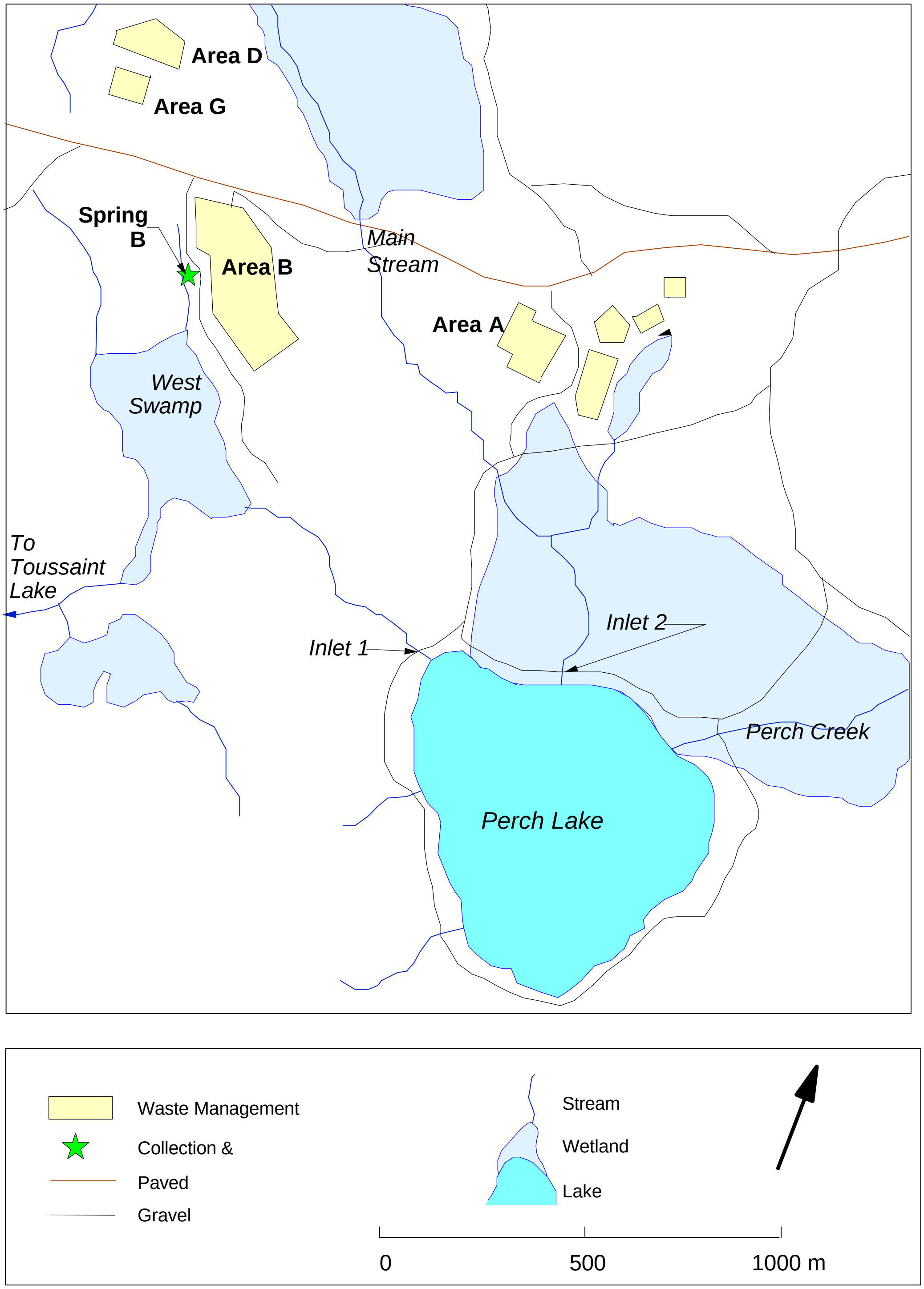


Figure 1: Drainage areas in the vicinity of Waste Management Area B.

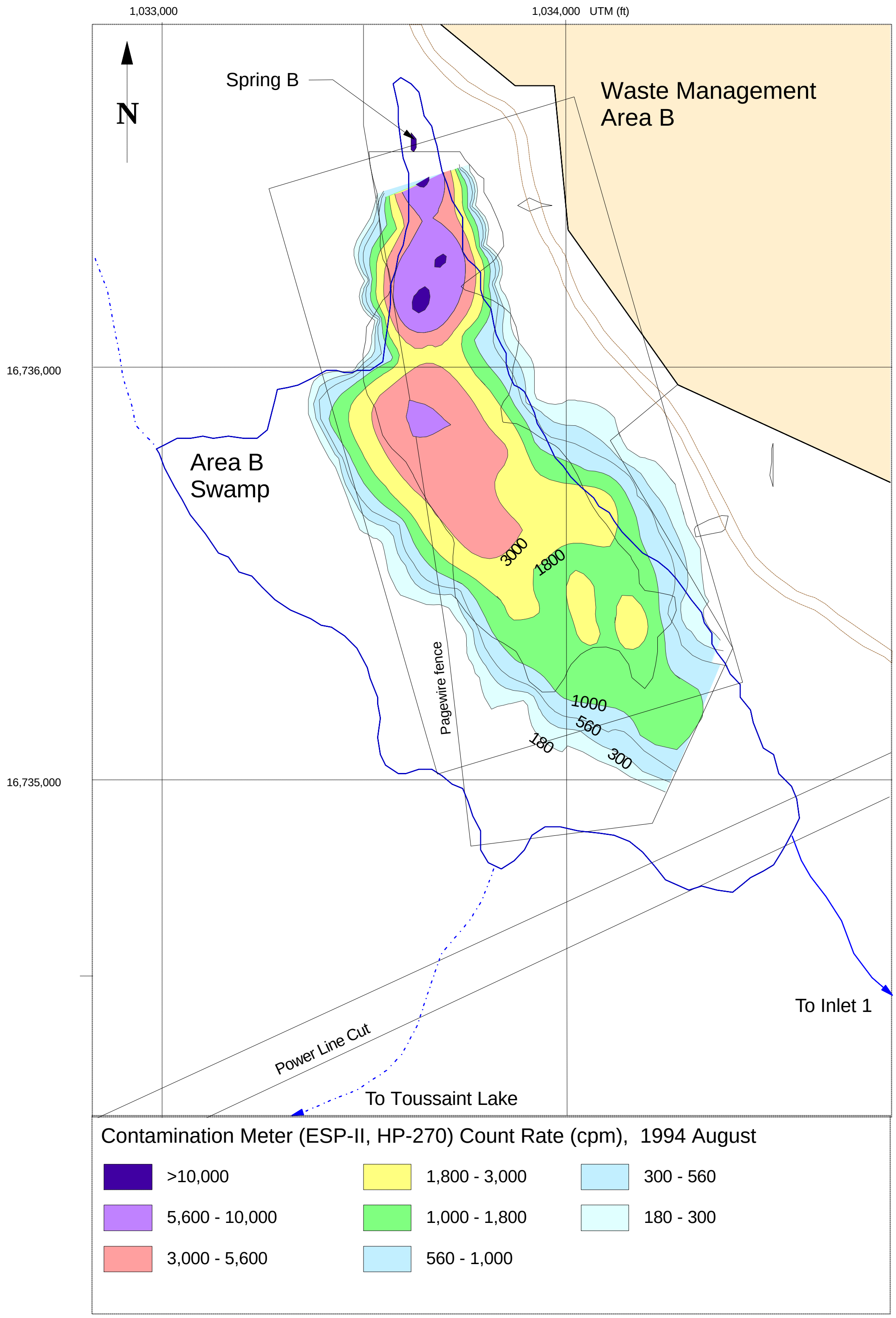


Figure 2: West Swamp contamination plume

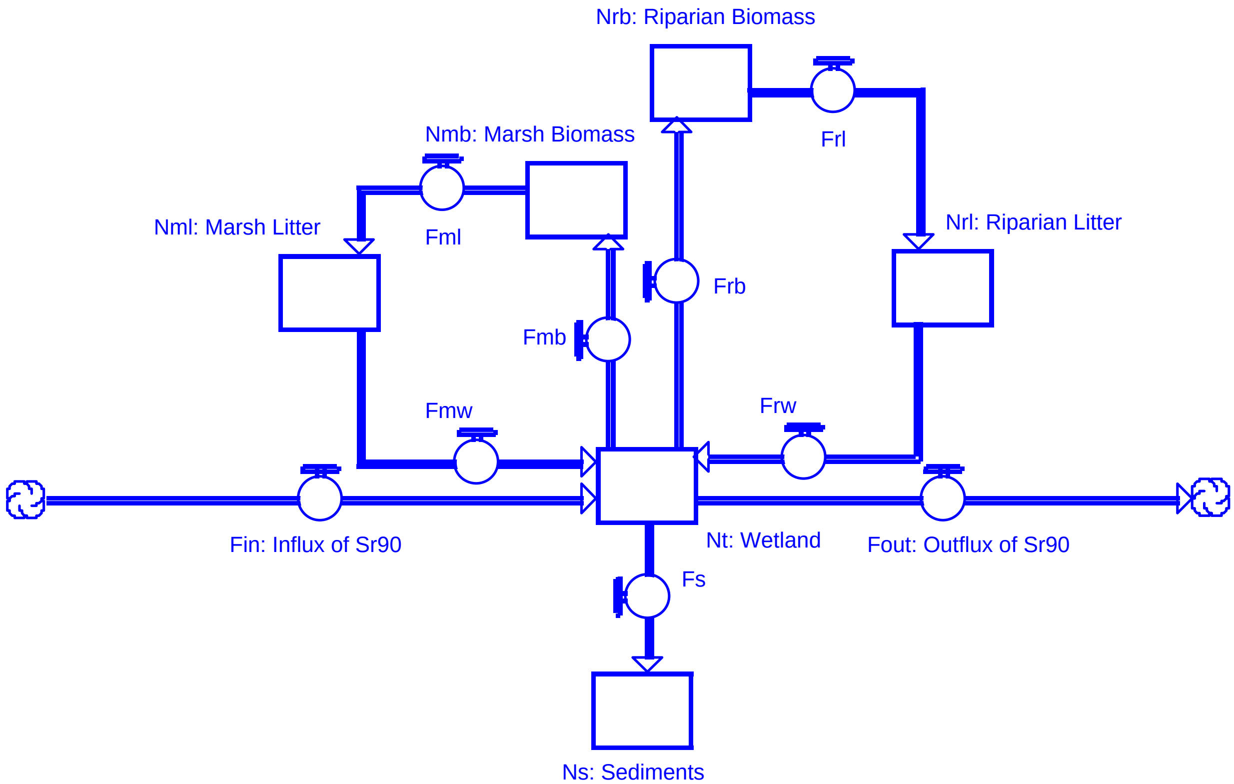


Figure 3: Conceptual compartment model of the West Swamp

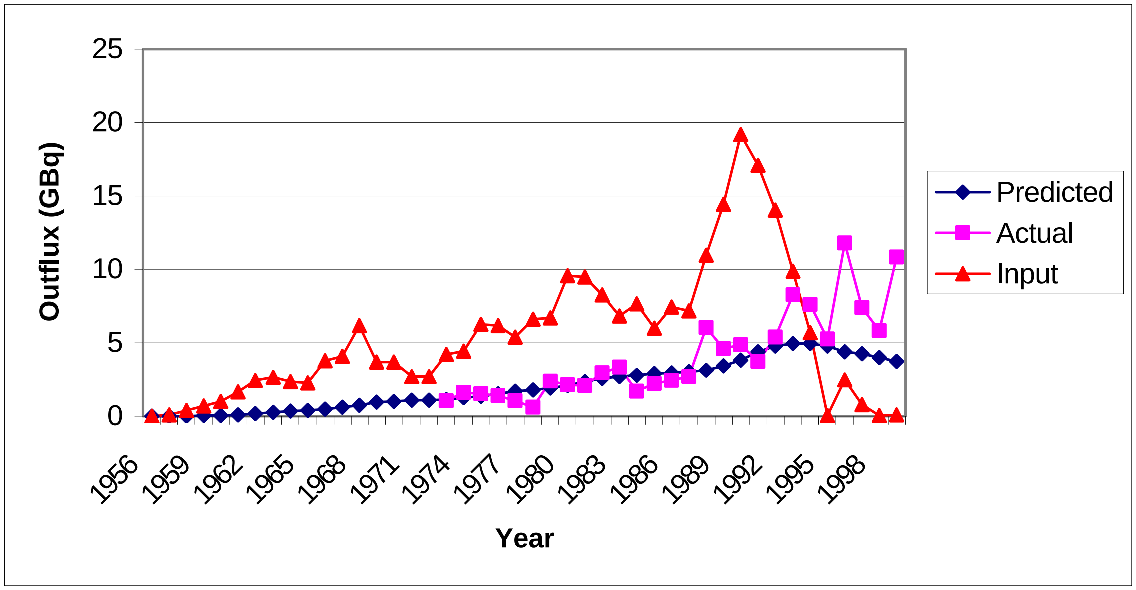
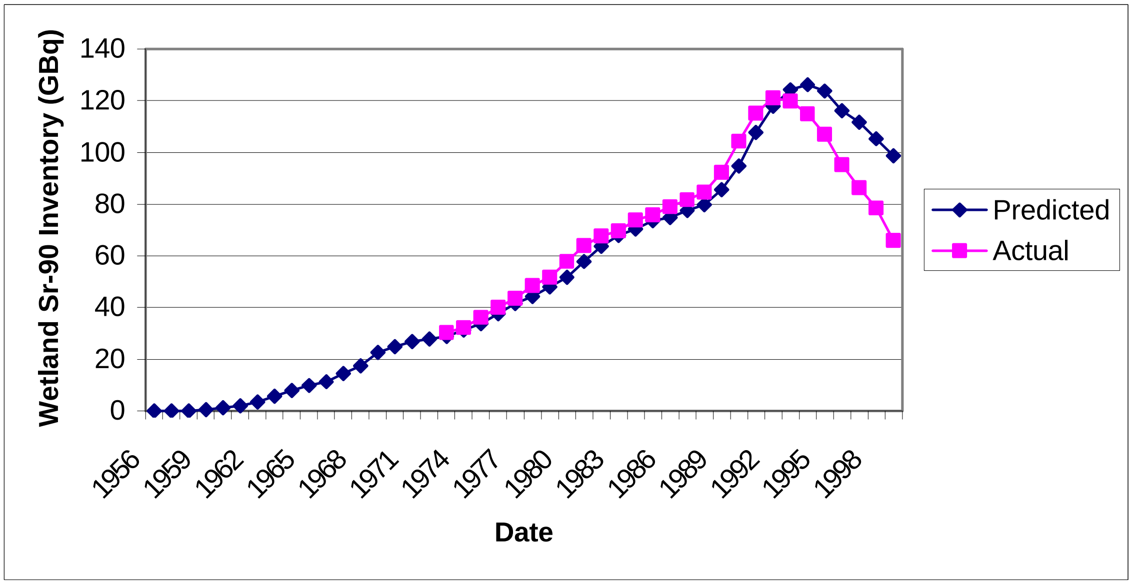


Figure 4a:Actual and predicted ^{90}Sr flux out of the West Swamp – final model



(Input flux of ^{90}Sr shown for comparison)

Figure 4b:Aggregate ^{90}Sr inventory in the West Swamp – final model

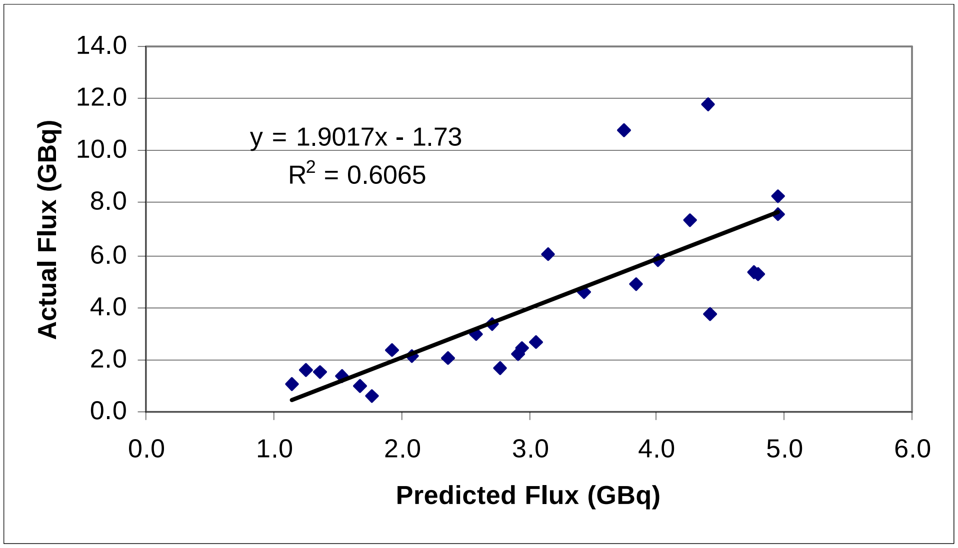


Figure 4c:Actual versus predicted ^{90}Sr flux – final model
(Regression analysis shown for comparison)

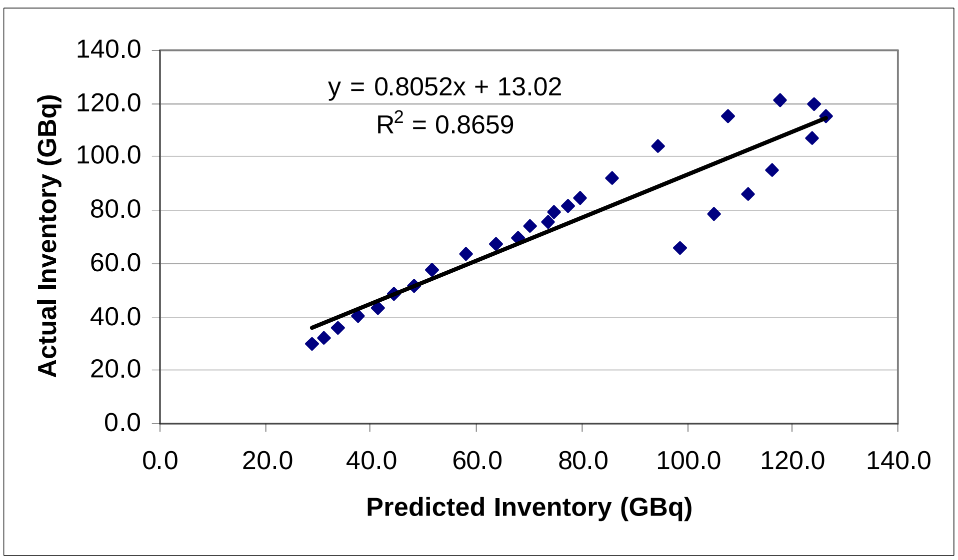


Figure 4d:Actual versus predicted aggregate ^{90}Sr inventory– final model
(Regression analysis shown for comparison)

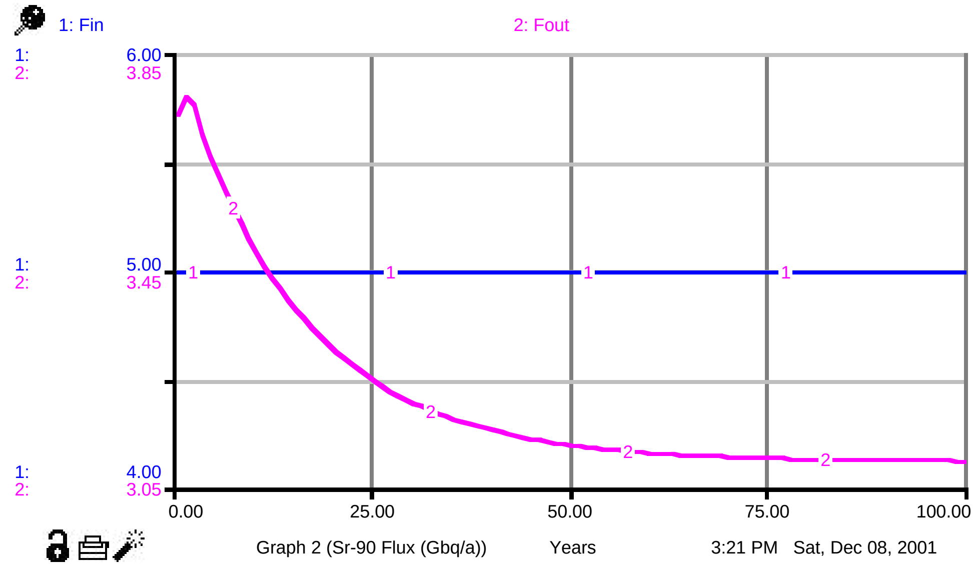


Figure 5a: ^{90}Sr outflux predictions (GBq a^{-1}) – no Spring B treatment

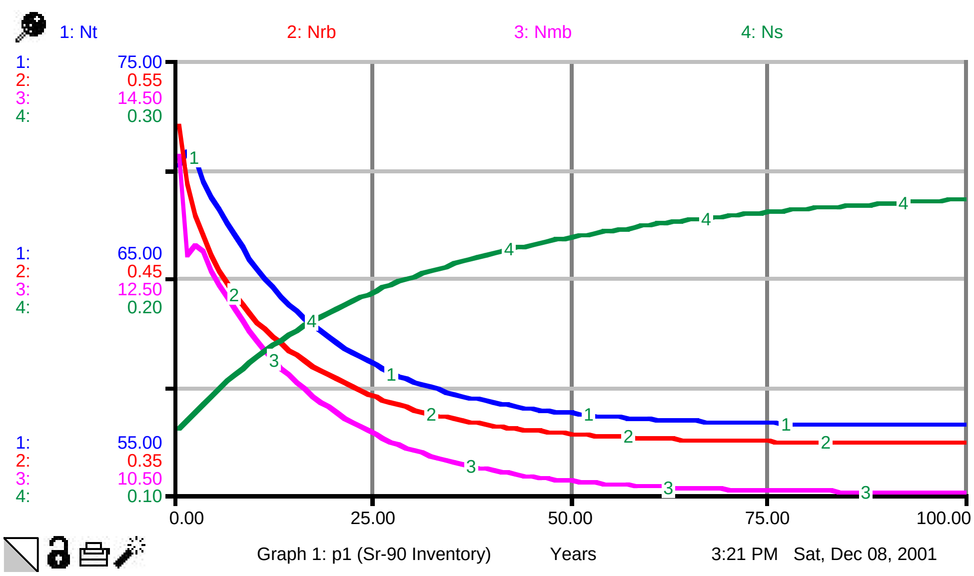


Figure 5b: ^{90}Sr inventory predictions (GBq) - no Spring B treatment

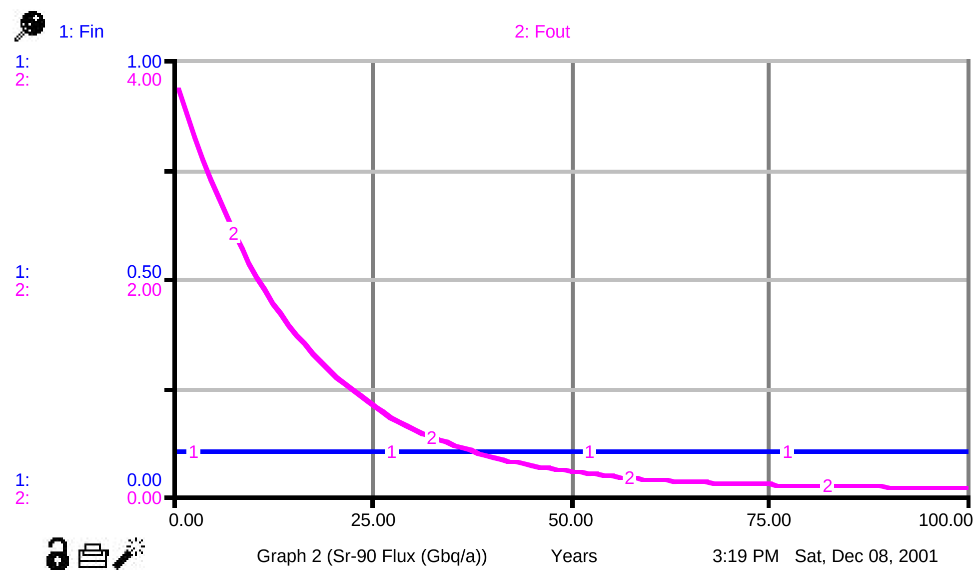


Figure 6a: ^{90}Sr outflux predictions (GBq a^{-1}) – continued Spring B treatment

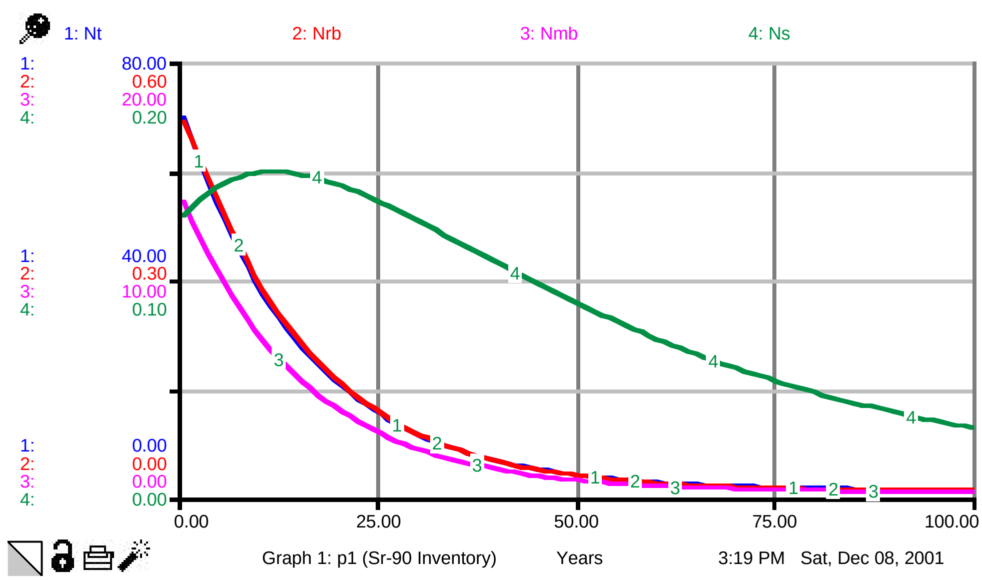


Figure 6b: ^{90}Sr inventory predictions (GBq) - continued Spring B treatment

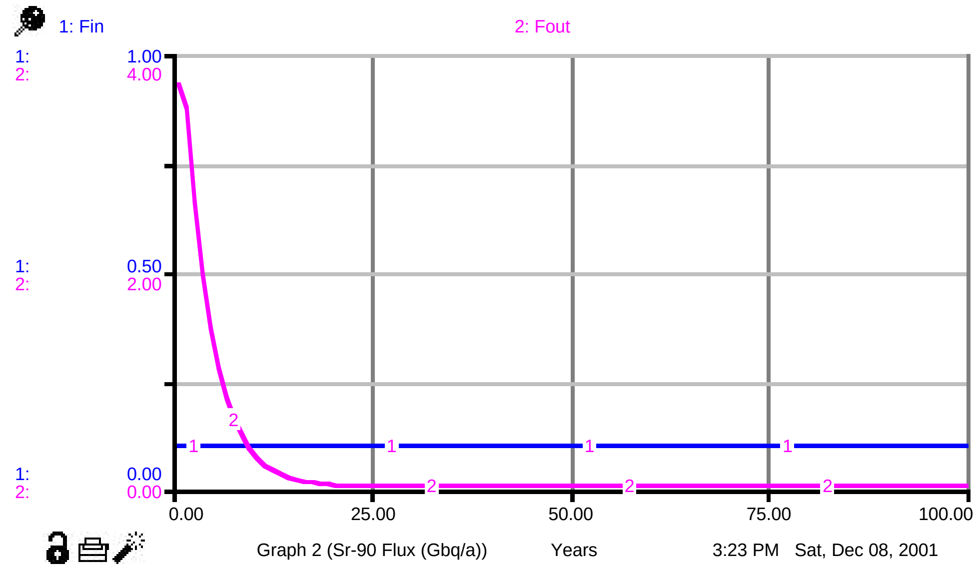


Figure 7a: Effect of harvesting cattails on ^{90}Sr outflux

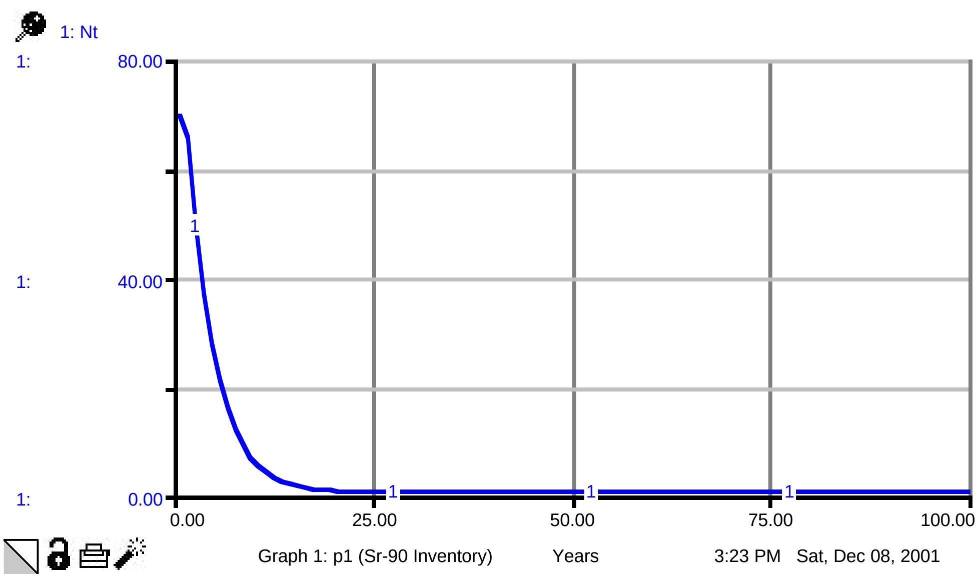


Figure 7b: Effect of harvesting cattails on ^{90}Sr wetland inventory

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APPENDIX A – STELLA® MODEL AND EQUATIONS

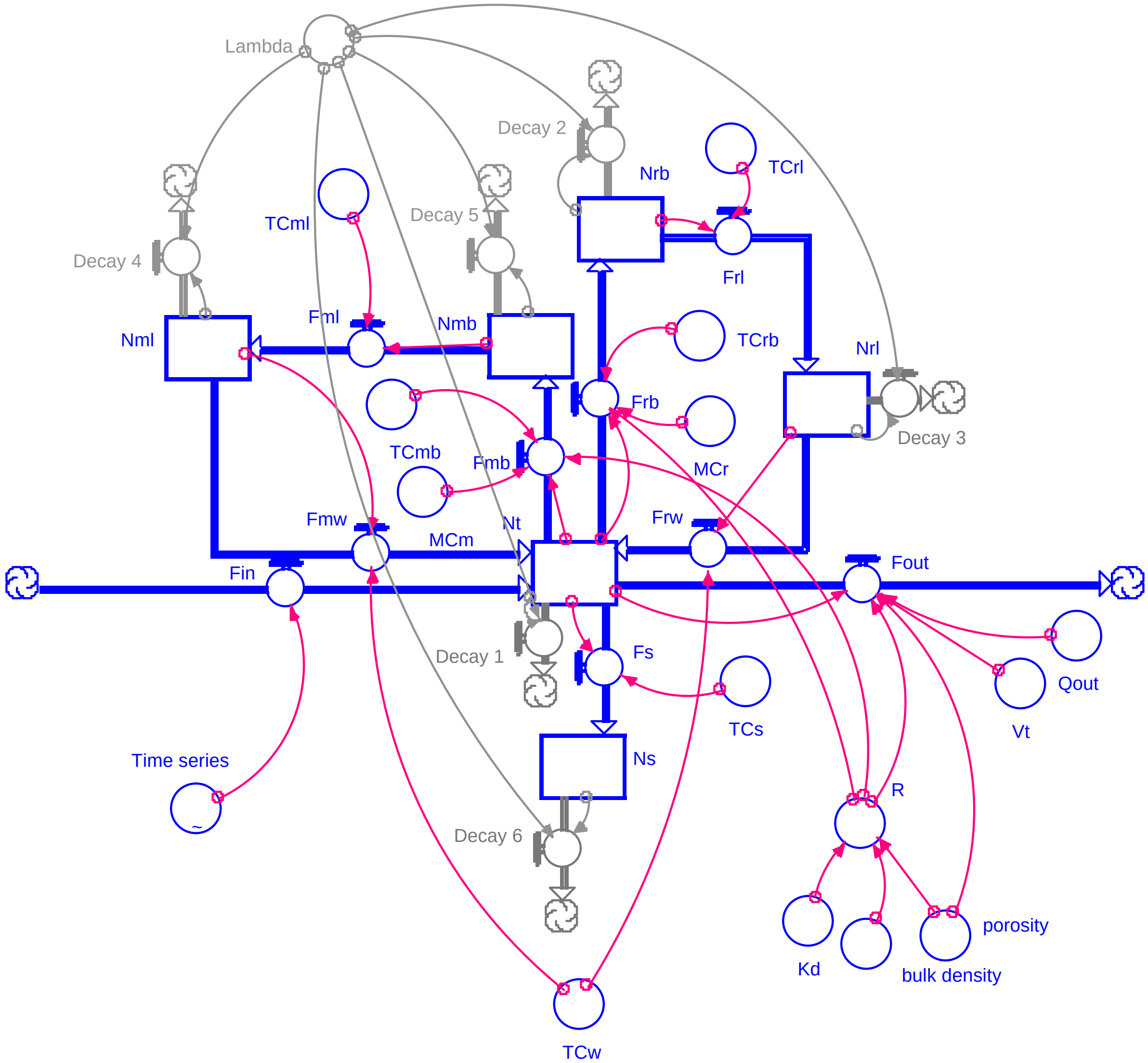

Figure A.1: The complete wetland model

STELLA® Model Equations

```
Nmb(t) = Nmb(t - dt) + (Fmb - Fml - Decay_5) * dt
INIT Nmb = 0
Fmb = (Nt/R)*TCmb*MCm
Fml = Nmb*TCml
Decay_5 = Nmb*Lambda
Nml(t) = Nml(t - dt) + (Fml - Fmw - Decay_4) * dt
INIT Nml = 0
Fml = Nmb*TCml
Fmw = Nml*TCw
Decay_4 = Nml*Lambda
Nrb(t) = Nrb(t - dt) + (Frb - Frl - Decay_2) * dt
INIT Nrb = 0
Frb = (Nt/R)*TCrb*MCr
Frl = Nrb*TCrl
Decay_2 = Nrb*Lambda
Nrl(t) = Nrl(t - dt) + (Frl - Frw - Decay_3) * dt
INIT Nrl = 0
Frl = Nrb*TCrl
Frw = Nrl*TCw
Decay_3 = Nrl*Lambda
Ns(t) = Ns(t - dt) + (Fs - Decay_6) * dt
INIT Ns = 0
Fs = Nt*TCs
Decay_6 = Ns*Lambda
Nt(t) = Nt(t - dt) + (Fin + Frw + Fmw - Fout - Frb - Decay_1 - Fmb - Fs) * dt
INIT Nt = 0
Fin = 1*Time_series
Frw = Nrl*TCw
Fmw = Nml*TCw
Fout = (Nt*Qout)/(R*Vt*porosity)
Frb = (Nt/R)*TCrb*MCr
Decay_1 = Nt*Lambda
Fmb = (Nt/R)*TCmb*MCm
Fs = Nt*TCs
bulk_density = 140
Kd = .32
```

Lambda = .0239

MCm = .882

MCr = .118

porosity = .82

Qout = 26950

R = 1+((bulk_density*Kd)/porosity)

TCmb = .2

TCml = .35

TCrb = .02

TCrl = .18

TCs = .0001

TCw = .755

Vt = 16000

Time_series = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.08), (2.00, 0.41), (3.00, 0.69), (4.00, 0.98), (5.00, 1.65), (6.00, 2.45), (7.00, 2.65), (8.00, 2.35), (9.00, 2.24), (10.0, 3.79), (11.0, 4.09), (12.0, 6.18), (13.0, 3.71), (14.0, 3.68), (15.0, 2.70), (16.0, 2.70), (17.0, 4.20), (18.0, 4.46), (19.0, 6.27), (20.0, 6.18), (21.0, 5.41), (22.0, 6.63), (23.0, 6.72), (24.0, 9.58), (25.0, 9.47), (26.0, 8.26), (27.0, 6.81), (28.0, 7.65), (29.0, 5.98), (30.0, 7.42), (31.0, 7.18), (32.0, 11.0), (33.0, 14.4), (34.0, 19.2), (35.0, 17.1), (36.0, 14.1), (37.0, 9.85), (38.0, 5.64), (39.0, 0.03), (40.0, 2.64), (41.0, 0.55), (42.0, 0.06), (43.0, 0.08)

APPENDIX B: OBSERVED ^{90}SR IN THE WEST SWAMP

	^{90}Sr Flux ($GBq \cdot a^{-1}$)				Swamp Inventory (GBq)	
Year	**Spring B**	**Removed by Treatment**	**Net Flux to West Swamp**	**Inlet 1**	**Annual Change**	**Cumulative Decay Corrected**
1957	0.1		0.1		0.0	
1958	0.4		0.4		0.3*	
1959	0.7		0.7		0.5*	
1960	1.0		1.0		0.8*	
1961	1.6		1.6		1.3*	
1962	2.5		2.5		1.9*	
1963	2.7		2.7		2.1*	
1964	2.4		2.4		1.8*	
1965	2.2		2.2		1.7*	
1966	3.8		3.8		3.0*	
1967	4.1		4.1		3.2*	
1968	6.2		6.2		4.8*	
1969	3.7		3.7		2.9*	
1970	3.7		3.7		2.9*	
1971	2.7		2.7		2.1*	
1972	2.7		2.7		2.1*	
1973	4.2		4.2	1.1	3.1	30.2*
1974	4.5		4.5	1.6	2.9	32.3
1975	6.3		6.3	1.5	4.7	36.2
1976	6.2		6.2	1.4	4.8	40.2
1977	5.4		5.4	1.0	4.4	43.6
1978	6.6		6.6	0.6	6.0	48.6
1979	6.7		6.7	2.4	4.3	51.7
1980	9.6		9.6	2.1	7.4	57.9
1981	9.5		9.5	2.1	7.4	63.9
1982	8.3		8.3	3.0	5.3	67.7
1983	6.8		6.8	3.3	3.5	69.5
1984	7.6		7.6	1.7	6.0	73.8
1985	6.0		6.0	2.2	3.8	75.8
1986	7.4		7.4	2.4	5.0	79.0
1987	7.2		7.2	2.7	4.5	81.6
1988	11.0		11.0	6.0	4.9	84.6
1989	14.4		14.4	4.6	9.8	92.3
1990	19.2		19.2	4.9	14.3	104.4
1991	17.1		17.1	3.7	13.3	115.2
1992	14.1		14.1	5.4	8.7	121.1
1993	12.3	2.4	9.9	8.3	1.6	119.8
1994	10.3	4.7	5.6	7.6	-1.9	115.0
1995	3.7	3.7	0.0	5.2	-5.2	107.0
1996	7.1	4.5	2.6	11.8	-9.3	95.2
1997	5.2	4.7	0.5	7.4	-6.8	86.3
1998	4.5	4.4	0.1	5.8	-5.8	78.4
1999	4.8	4.7	0.1	10.8	-10.7	65.8

(* denotes an estimated value)