Computer modeling and scientific visualization of the St. Johns Landfill surface water environ

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1. Introduction

This document constitutes the final report for the computer modeling and scientific visualization component of the project "Integrated Analysis of the St. Johns Landfill Environ"[1]), which was conducted for METRO by the Center for Coastal and Land-Margin Research (CCALMR) of the Oregon Graduate Institute of Science & Technology (OGI).

The objectives of our research were two-folded:

- to develop a prototype of the *Electronic St. Jonns Landfill Environ* (Section 2), a computer tool designed to assist:

  (a) the characterization of circulation and water quality in the Columbia and North sloughs (Section 3) and in the Smith and Bybee lakes; and

  (b) to assess the interactions of the St. Johns landfill with its surface water environ;

- to develop and assess a novel technique for the time-explicit characterization of contamination sources (Section 4).

The perceived contributions of the project are summarized in Section 5.

All graphical results are presented in digital form, as a part of the *Electronic St. Johns Landfill Environ.*

1. The *environ* of the St. Johns Landfill is defined, for the purposes of the present report, as the landfill and the surrounding sloughs and lakes.

2. The *Electronic St. Johns Landfill Environ*

2.1 Concept

Our objective was to integrate field data, computer models, and computer graphics into an user-friendly and scientifically-sound framework for the analysis of the water quality surrounding the SJLE.

A prototype version of this tool, denoted *Electronic St. Jonns Landfill Environ* (ESJLE), was implemented, and is available for examination at OGI. Installation at METRO can be made any time, at request (access to one of METRO's UNIX workstations, for a period no longer than one week, will be required for the installation).

The following sections discuss the design and present functionality of ESJLE, review the ESJLE supporting models, and illustrate the use of both in the analysis of circulation and transport of the Columbia and North sloughs.

2.2 Design considerations

Our broad design of the ESJLE calls for three "modes" of operation:

- analysis of existing information (field data and modeling results);
- model set-up and execution;
- learning (about the St. Johns landfill and its environ).

Only one of these modes (analysis of existing information) was implemented in this project.

To access ESJLE, follow these steps:

- locate the proper directory: cd /data/y/landfill [return]

- set the environment: setenv SJHOME /data/y/ [return]

- call the interface: sj [return]

2.3 Data and data access

Data available for the surface water environ of the St. Johns landfill is quite diverse. The ESJLE provides the means to organize and facilitate the access to relevant data., through specially built graphical interfaces and data access protocols.

The data access protocol incorporates both field data and model results/interpretations. Access to the information is structured as follows:

- Field data
  - Bathymetry
  - Elevations
  - Velocities
  - Hydrolab data
  - Miscellaneous water quality
- Processed data
  - Tidal constituents
- Modeling results
  - Circulation
  - Transport
  - Assessment of inverse methods

Upon selection, data are displayed graphically, in pre-arranged formats. Modeling results are often shown in the form of computer animations. Sections 4 and 5 discuss examples of access to both static plots and animations.

2.4 Support modeling techniques and tools

Several existing CCALMR models and auxiliary tools were available for the present project. These models and tools, described in the following sections, are a part of ACE (Analysis of Coasts and Estuaries). ACE is a finite-element based computational structure for the integrated simulation, interpretation, and visualization of pathways of water, sediments, and natural and anthropogenic elements in coastal-related land-margin systems.

Like ESJLE, the use of all graphical tools referred below (ACE/gr, ACE/gredit, and ACE/vis) require UNIX workstations or X-terminals.

2.4.1 Circulation model

Three models are currently available at CCALMR that can be used to simulate aspects of the circulation of the St. Johns landfill surface water environ:

- $RITA_{2V}$ (Fortunato and Baptista 1993): provides a time-domain representation of (at user's discretion) of cross-section averaged or laterally-averaged flows.
- TEA-NL (Westerink et al. 1988, Baptista et al 1989): provides a frequency-domain representation of depth-averaged flows.
- ADCIRC (Westerink et al. 1993): provides a time-domain representation of depth-averaged flows.

A fourth model (Beck and Baptista, in progress) is being developed, under separate sponsorship. Like ADCIRC, the model is depth-averaged and is set in the time-domain, but, unlike ADCIRC, it will allow the effective simulation of wetting and drying.

We chose to use TEA-NL during this project, due to our interest in understanding the tidal dynamics of the Columbia and North sloughs, and to practical considerations regarding the link to the transport models.

2.4.2 Transport model

Four models are currently available at CCALMR that can be used to simulate aspects of the flushing characteristics and water quality of the St. Johns landfill surface water environ:

- ELA (Baptista et al. 1984): simulates depth-averaged transport of conservative tracers.
- ELAsed (Barros and Baptista 1989): simulates depth-averaged transport of cohesive sediments.
- ELAcol (Baptista et al. 1989): simulates depth-averaged transport of fecal contaminants.
- ELAmet (Wood and Baptista 1993): simulates depth-averaged transport of tracer metals.

ELA was used throughout the project, as we concentrated on a conservative tracer (conductivity).

2.4.3 Exploratory data analysis

ACE/gr (Turner 91) is an XY plotting and exploratory analysis tool. A few of its features are:

- A convenient point- and-click interface.
- Polynomial regression, splines, running averages, DFT/FFT, cross/auto-correlation.
- Plots up to 10 graphs with 30 data sets per graph.
- User-defined scaling, tick marks, labels, symbols, line styles, colors.
- Batch mode for unattended plotting.
- Read and write parameters used during a session.
- Hard-copy support for Postscript, HP-GL, and FrameMaker .mif format.

2.4.4 Grid generation

ACE/gredit is a tool for the flexible, interactive, and semi-automatic generation of two-dimensional triangular finite element grids, designed to support studies of estuarine and coastal dynamics and water quality.

A typical grid is built based on a domain outline (e.g., a shoreline) and an unstructured set of points, each associated with a fundamental property of the domain (e.g., water depth). The user can retain full control of the grid design, while letting the computer perform the mechanic, time-consuming tasks. Alternatively, fully automatic grid generation is possible.

A menu-driven interface makes the use of ACE/gredit fairly intuitive and self-explanatory.

2.4.5 Scientific visualization

ACE/vis is a tool for the flexible, interface, dynamic (mapping) of hydraulic and environmental phenomena in coastal and land-margin systems. The visualization is based on the description of the relevant phenomena as provided by numerical models or by experimental data.

Phenomena that ACE/vis specifically addresses and that are relevant to this project include tidal propagation, estuarine and fluvial circulation, and transport of conservative and non-conservative tracers.

A user-friendly interface provides the user with broad control on what features to show, what data to use, and what time-window to select.

3. Circulation and transport in the Columbia and North sloughs

Levels and flows in the Columbia and North sloughs are controlled by a combination of forcings, including:

- levels at the confluence with the Willamette River, which incorporate the effects of both the Willamette and Columbia rivers;
- pumping from the Upper Columbia Slough;
- combined sewer overflows.
- occasional discharges from the Smith and Bybee lakes;

The joint forcing of the Willamette and Columbia dominates the dynamics of the levels in the sloughs. To understand the nature of this forcing, it is instructive to examine the surface water records at 11 stations in the Columbia River (6), Willamette River (1), Columbia Slough (2), North Slough (1) and Bybee lake. You can do this through ESJLE, by following these steps:

- select "field data" in the top panel; a map showing the location of the 11 stations will appear in the main panel; station names will also appear, if "display labels" is selected in the bottom panel.

- press the marker identifying the location, to examine elevations at an individual station; by default, all elevation data available at the selected station will be displayed[1];

At Astoria, at the mouth of the Columbia, the influence of ocean tides is clearly dominant, with peak-to-peak amplitudes of the order of 3m. As we progress upstream (Wauna, Longview, and Vancouver), tidal amplitudes decrease and river-induced fluctuations become more apparent. Both tidal and riverine influences are significant at the USGS station in the Willamette River, and extend to the upstream ends of the North (East end) and Columbia sloughs (Lombard St. and St. Johns bridges).

A rigorous separation of tidal and riverine influences was considered beyond the scope of this project. Rather, an harmonic analysis was performed that partially combines both effects. Results can be examined through ESJLE, by following these steps:

- select "processed data" in the top panel; a map showing the location of the stations where harmonic analysis was performed will appear in the main panel; station names will also appear, if "display labels" is selected in the bottom panel.

- press the marker identifying the location, to examine harmonic analysis results for an individual station; two types of information will be displayed: (a) a table showing amplitudes and phases for all frequencies used in the analysis, and (b) plots representing the raw data, data obtained by consecutive harmonic analysis and synthesis, differences can be loosely interpreted as effects that are non-periodic (i.e., non-tidal and including only the non-periodic component of the riverine signal)

The relevance of the harmonic analysis, as performed, is that it provides an expedite means to extrapolate level information in time, at a particular station. However, it is important to recognize that this extrapolation is only approximate, because it excludes non-periodic forcings. Hence, while the time extrapolation will often be rather satisfactory for tidal amplitudes and phases, it will <u>not</u> be reliable for total water depth.

While no rigorous calibration was performed, several TEA-NL simulations were used to provide insight on qualitative patterns of circulation in the slough, and to support our research on source characterization. To examine the results of these simulations:

- select "model results" in the top panel; a pop-up with a variety of choices will appear;

1. ACE/gr manages the reading and display of the data; familiarity with ACE/gr commands (Turner 19**) allows the user to flexibly change the default display, and analyze the data statistics.

- select "March 2, 1991" under "circulation"; an animation will appear, showing simulated circulation in the Columbia and North sloughs, for Willamette/Columbia elevations representative of the period March 2-7, 1991, [which corresponds to a Portland State University dye experiment, discussed later].

- select "Nov. 6, 1993" under "circulation"; a similar animation will appear for the period Nov 6-13, 1993, which partially corresponds to a METRO/PSU/OGI survey discussed later

From comparison with field data (stations at the Lombard St. and St. Johns bridges, and at the East end of the North Slough), we find that our simulations tend to underpredict frictional effects. Even so, simulations suggest that Willamette/Columbia-induced circulation is significant in the lower Columbia Slough, but quite negligible upstream of the Burlington Av. bridge and in the North and Blind sloughs. Both these conclusions are consistent with observations.

While the Willamette/ Columbia forcing dominates the water levels and tidal circulation in the sloughs, intermittent discharges (from CSOs and the upstream ends of the Columbia and North sloughs) may significantly impact net flushing. Linked TEA-NL and ELA simulations were used to gain insight on this impact. In particular, we examined the of a 250 cfs discharge at the upstream end of the Columbia Slough, as proposed in the City of Portland's Columbia Slough Program Plan. Results can be observed though ESJLE:

- select "model results" in the top panel; a pop-up with a variety of choices will appear;

- select, under "circulation", "Nov. 6, 1993, bc=0cfs" and then "Nov. 6, 1993, bc=250cfs"; animations will result from each selection; observe differences in velocity fields, and in the extent of upstream propagation of the tides;

- select "flush curve"; a static plot will result; observe the drastically different removal rates of a same amount of tracer introduced instantaneously in the upstream end of the Columbia slough, with and without upstream flows;

- select "Nov. 6, 1993, bc=0cfs" and then "Nov. 6, 1993, bc=250cfs", under "transport"; animations will result from each selection; observe differences in concentration fields of a generic conservative tracer, that result from the presence or absence of "contaminated" sources at the upstream end of the Columbia slough;

TEA-NL and ELA were also used to reproduce the dye experiment conducted by PSU in March 1991. Results can be examined though ESJLE:

- select "model results" in the top panel; a pop-up with a variety of choices will appear;

- select "dye" and "dye - longitudinal plot", under "transport"; a time-varying comparison of dye observations and ELA simulations will appear., showing reasonable qualitative agreement.

While none of the results shown above are intended as calibration/validation, they are illustrative of the potential of our models to represent circulation and transport properties in the system. A reliable calibration and validation of the models can be performed with the available data, and would constitute a logical next step.

4. Source characterization by inverse methods

4.1 Concept and method

The diversity of potential sources makes it difficult to do a traditional "forward simulation" of the fate of environmental tracers in the St. Johns landfill. Indeed, "forward simulations" presume a knowledge of the loads of tracer in space and time, which is lacking.

As an alternative to "forward simulation", we proposed to develop and test an "inverse method" to characterize the spacial and temporal distribution of loads.

The concept of the inverse method is simple:

- time-series of concentration of the selected tracer(s) are measured at several stations in the sloughs; these time-series constitute a "fingerprint" of the initial conditions and loads for the period of observation;
- several "forward" numerical simulations are made for the same period, each representing the concentration fields associated with a set of "unit forcings" located appropriately throughout the domain;
- concentrations at each observation station are represented as a weighted summation of the concentrations obtained numerically for each "unit forcing";
- weighting factors in the summation are unknown a priori; they must be calculated so as to minimize errors between the weighted summation and the actual observations at the stations;
- once the weighting factors are computed, the weighted summation is fully defined at any point of the domain, including boundaries; time and space characteristics of the tracer loads can therefore be determined.

An innovative technique, based on a traditional singular value decomposition method, was developed to implement the inversion (Wang and Baptista, in prep.). The method was first analyzed diagnostically, and was then partially assessed in the context of a specially-designed field survey.

4.2 Diagnostic assessment of the method

For the diagnostic assessment of the method, we built a "synthetic reality". i.e., we used a numerically computed flow field and a controlled source scenario to define in space and time a synthetic concentration field of a conservative tracer. This concentration field was "sampled" at selected locations, constituting "synthetic field stations". Time-histories at synthetic field stations, sometimes after controlled introduction of "synthetic observation errors", were used to recover the imposed source scenario.

The following conclusions/guidelines apply:

- under the controlled conditions of the diagnostic analysis, source scenarios can be recovered almost perfectly if the synthetic observations are not contaminated by errors, and if the number of observation stations equals the number of sources to identify;
- the inversion method is robust enough to "filter" out random or otherwise non-biased observation errors, if the time interval of sampling is appropriately (often, an order of magnitude) denser than the time-interval at which we want to recover the time-history of the sources;
- the inversion method is robust enough to identify more sources than the number of sampling stations; however, the larger the ratio between the number of sources and sampling stations, the less time-resolution should be expected from the inversion;
- the inversion method inherently provides a mechanism (condition number) to guide the choice of the location of the sampling stations;

Results of the diagnostic assessment tests can be examined through ESJLE. For this, select "model results", and browse through the options under "diagnostic".

4.3 Field application

[section in preparation; results available through ESJLE]

5. Final considerations

The primary practical contribution of this project was the development of a prototype version of the *Electronic St. Johns Landfill Environ (ESJLE).*

ESJLE is a menu-driven "organizer" of information on field data, modeling, and general understanding, and should significantly enhance the ability of researchers, consultants, managers, and regulators to understand and interact with the system.

However, the long-term usefulness of ESJLE will depend on the sustained ability to maintain and update this tool, and of the range of users that are allowed to contribute to and access the information available at any time. We propose that a strategy to approach these issues be jointly sought by METRO, OGI/CCALMR, and eventually other interested parties, if the concept and current functionality of ESJLE warrant such interest.

The primary theoretical contribution of this project was the development and partial assessment of an innovative method for time- and space-explicit source characterization. The method has shown significant promise, but refinements are necessary to make it into a practical tool. We will continue our research on the topic, in the context of the Ph.D. thesis of the first author.

The numerical simulations of flow and transport that were developed in support of both the above contributions provide useful qualitative insight on the functioning of the overall system. However, none of the models used was systematically calibrated and validated. We therefore do not recommend that the simulations shown be interpreted in a strict quantitative sense. We anticipate that models will be more systematically calibrated n the context of the Ph.D. thesis of the first author.

Two conference abstracts were submitted in the sequence of the present work (Baptista et al. 1994 and Wang et al. 1994).

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