Understanding the Dynamics of Coastal Resources Management: exploring past experience and moving toward an ecosystem management approach[1]

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Abstract

System dynamics concepts and methods are rarely referenced in the field of coastal resources management, even though coastal systems and decision-making are dynamically complex and the SD literature offers a rich and relevant body of theory, practice and models. Recent work in the theory of ecosystem management calls for the use of modeling and is becoming of increasing interest to coastal managers. A simple stock and flow model of coastal management is presented that is drawn from the legislative design of one of the oldest and certainly successful U.S. state programs, Rhode Island's Coastal Resources Management Program. This model exhibits several dynamic behaviors intuitively familiar to coastal managers. Model runs are presented using parameters taken from the Rhode Island case, including runs with and without the coastal management program in place. These results are compared with performance data from the 35 year Rhode Island coastal program's permit data base, and closely reproduce long term trends in key variables. The forward-looking scenarios are utilized to suggest approaches for the state program as it enters the new century.

Key words: coastal management, ecosystem management, Rhode Island, Coastal Resources Management Program, special area management plans, resilience.

Introduction: Coastal management in the 21st century

The Working Group on Ocean and Coastal Management, in preparation for the 2002 World Summit on Sustainable Development, proposed the ambitious goal that 20% of the 173 national coastlines should be under management by 2012 and 60% by 2022. (Global Conference, 2001). The optimism of these goals is counterpoised by the observation of a long-standing expert in the field who perhaps speaks for many of his peers by drawing the dismal conclusion that "The practice of Integrated Coastal Management (ICM) is learning relatively little from its 35 years of experience involving approximately 698 ICM efforts at all levels of governance, in all parts of the world, in all types of political regimes, in all types of environments, and at all levels of national economic development. ICM practitioners appear to have little time (and often facilities) for information searches and reading to find answers to specific questions they have to design or improve their program." (Sorensen, 2000.)

The United States has already exceeded these targets, and has been a pioneer in coastal management policy and program development since the adoption of the federal Coastal Zone Management Act in 1972. The voluntary program now covers 34 states and territories.

State Programs take three basic forms:

(A) Local Programs: State establishment of criteria and standards for local implementation, subject to administrative review and enforcement.
(B) Direct State land and water use planning and regulation.
(C) Networked Programs: State administrative review for consistency with the management program of all development plans, projects, or land and water use regulations proposed by any State or local authority or private developer.

Virtually the entire national shoreline, encompassing 95,376 miles including the Great Lakes region are managed through state programs approved by the federal Office Ocean and Coastal Resources Management.

The U.S. Commission on Ocean Policy (2004) recently completed a thorough review of marine and coastal programs and concluded that there is much more to be done in coastal management even in the U.S. context:

> To more effectively manage coasts, states need a stronger capacity to plan for and guide growth---one that incorporates a watershed approach to govern coastal and ocean resources. In addition, to assist states in such development and support the move toward an ecosystem-based management approach, federal area-based coastal programs should be consolidated to better integrate and capitalize on the strengths of each. [2004:109]

The vision of the U.S. Commission on Ocean Policy has the nation moving toward an ecosystem approach that will encompass coastal watershed management and coordinated, policies across agencies and levels of government and a seamless implementation approach that eliminates duplication and fosters synergy including in trans-boundary and international situations. In addition:

> Social and natural resource assessment and planning at the watershed scale should become a high priority in each state's program...The Coastal Zone Management Act can be strengthened by developing strong, specific, measurable goals and performance standards that reflect a growing understanding of ocean and coastal environments, the basic tenets of ecosystem-based management, and the need to manage growth in regions under pressure from coastal development. [2004:112]

Curiously, the Commission does not define what it means by ecosystem-based management nor does it specifically declare what it considers to be standards of practice or good models.

So what is ecosystem management? Grumbine [1994:31] provides a robust definition that is a good place to start:

> Ecosystem management integrates scientific knowledge of ecological relationships within a complex sociopolitical and values framework toward the general goal of protecting native ecosystem integrity over the long term.

While this definition arises from the field of conservation biology, it explicitly places humans and their institutions at the center of the discussion. He found ten dominant themes in his review of the literature up to the early 1990s. The first is:

> A systems perspective: focusing on any one level of the biodiversity hierarchy is not sufficient

If this true in the case of coastal resources management we would expect to find a burgeoning literature on systems approaches that could help explain what states should do as they reexamine their programs, but that, surprisingly, turns out not to be the case.

If we turn the clock back three decades, there was a measure of optimism about how modeling could help coastal managers at the 1972 Coastal Zone Workshop:

> A most powerful approach developed for attacking complex and otherwise intractable problems is the application of systems analysis...Managerial data requirements are far less demanding than those required for full scientific understanding. Well informed judgements and approximations often provide a quite adequate basis for decision-making...the progressive introduction of systematic approaches and of machine support for better human decision making can begin now, and would certainly result in substantial practical management improvements. (Ketchum, 1975)

Two decades later, a lone voice in the coastal management literature resurrects the call for a systems view of integrated coastal management (van der Weide, 1993). He begins with an appreciative review of the work of Forrester, and studies such as *The Limits to Growth* and *Beyond the Limits.* Van der Weide sought to focus more specifically on natural coastal systems, on the one hand, and the man-made world plus human activities in the other hand. Integrated coastal management occupies a role at the center “where relevant information lines come together and where strategies for sustainable development are prepared, based on a coherent knowledge basis, information systems and policy analysis.” (1993:134). His model offers a concise statement of the structure and dynamic interactions of the natural system components.

The last paragraph of the article, unfortunately, reduces all of the remaining work in coastal management to exercises in digital map-making: “The next stage is the development of a descriptive model of the activities in the coastal area, together with the supporting infrastructure. GIS (geographic information systems) is the appropriate tool to support such a description.” (1993:147) In this, van der Weide misses a key insight from *Beyond the Limits:* “Systems strongly resist changes in their information flows, especially in their rules and goals...only individuals, by perceiving the need for new information, rules and goals, communicating about them, and trying them out, can make the changes that transform systems.” (Meadows et.al., 1992:223)

A full text search for feedback thinking and system dynamics terms in recent issues of the two major coastal management journals *Coastal Management Journal (CMJ)* and *Ocean & Coastal Management (OCM)* generates few returns. The term “system dynamics” itself returned 7 articles in OCM (1993 to 2004) and “feedback returned” 58 articles. A scan of the text of those articles found 16 that employed some use of the concept “feedback”, such as a causal arrow or loop in an explanatory diagram describing a process, and most frequently these described a participatory approach either in concept or in a case example. However none explicitly show causal loop or stock and flow diagrams of the kind used in the SD literature and practice. A similar scan was performed with CMJ (1999-2003), which provided 13 returns for “feedback”. Again, several of these articles mention the term in the context of discussing participatory approaches and the policy process but none explicitly utilize SD concepts or methods.

Perhaps the most well known text in Integrated Coastal Management (Cicin-Sain and Knecht, 1998) contains no references, indexed terms or content sections relating to feedback thinking. A more recent text (Brown et. al. 2002) has no references or examples of causal loop or stock and flow models, but does include three indexed references to feedback, one relating to the social dimension, as well as numerous citations to the ecological economics literature and the concept of ecological resilience. The low utilization of SD concepts and techniques stands in contrast to the importance of scientific information and extensive use of physical and ecosystem modeling of specific issues in ICM to understand shore processes, storm hazards, estuary and bay dynamics and water quality, for example.

In 2000, Knecht and Cicin-Sain et.al. reported the results of a major study “Experiences with Ecosystem Management in the Delaware River”. Here they edge enticingly close to a feedback thinking and system dynamic perspective. In terms of definitions: “Developing knowledge of coastal ecosystem management requires first identifying the components and relationships within the ecosystem, both natural and human-made, and second understanding these relationships to apply management of them in an integrated, ecosystem context.” [2000:3] Having set this high bar of performance, however, the authors are disappointed to find that “in many of the cases, the implementation structures and processes that have been established have been weak and underfunded...”. Indeed, “while the management programs are rife with plans, public participation processes, goal-setting activities and the like, they are not closely connected to the regulatory activities on which they usually depend for their ultimate success.” [2000:9]

A key focus of the study was not on this core problem, but rather how “the coupling of GIS (Geographic Information Systems) with environmental models offers new opportunities to predict the consequences of management decisions”. [2000:42]

The feedback perspective in this paper insists that no amount of environmental modeling and GIS analysis used to create plans and make decisions can overcome a broken system that decouples policy from practice. This is another core insight from *Beyond the Limits:* “The world’s leaders do not know any better than anyone else how to bring about a sustainable society...it requires each of us to support leaders at all levels in their learning by creating an environment that permits them to admit uncertainty, conduct experiments, and acknowledge mistakes.” (1992:232)

Coastal management is becoming ecosystem management

Following up on the clue offered by the concept of “resilience”, the ecosystem management literature again offers coastal management some potential clarity and guidance. Coastal ecosystems located within or near urban settlements and are actively utilized. Within the broad scheme of ecosystem management, these can be called social-ecological systems, or SES.

Drawing again on the ecosystem management literature, a principal concern is the resilience, which has two main meanings. *Engineering resilience* is the notion that a system will return to a global equilibrium following a disturbance such as environmental pollution or over-harvesting, so the focus of environmental management is to restore the balance and maintain efficiency. *Ecological resilience*, on the other hand, is the recognition of the ability of ecosystems to shift their functions in response to perturbations, often irreversibly, thus the main management concern is maintaining the existence of a system's functioning. [Gunderson et. al. 2002]

Social-ecological systems, which combine engineered and natural system components, are complex in ways that make them especially unpredictable, thus "limit the usefulness of forecasting methods for the scientific study and management of regions in transition. Given these limits to understanding, we must focus on learning to live within systems rather than 'control' them". The goal then is "to prevent an SES from moving into undesirable configurations. It depends on the system being able to cope with external shocks in the face of irreducible uncertainty." [Walker, et. al. 2002] Resilient pathways cannot be computed, they are discovered in a process which has elements that are not entirely unfamiliar to coastal managers.

The recommended four steps are:

1. Answer the question " resilience **of** what?"by conducting a system modeling exercise with strong stakeholder involvement.
2. Answer the question "resilience **to** what?" by developing visions and a limited set of plausible future scenarios including trajectories that the stakeholders might want to drive the system toward.
3. Conduct a resilience analysis, with "discussions among stakeholders, policy makers, other local experts and scientists aimed at examining how the system will respond and change under the various scenarios". This is done "using a combination of modeling and non-modeling techniques."
4. Draw implications for management, having identified the processes that determine critical levels of the system's important control variables, and the corresponding set of actions that can enhance or reduce resilience.

The authors only offer stylized examples of how to do this analysis but the steps should be familiar to the SD community as part of the standard modeling process (Sterman, 2000:86) and in particular drawing upon group modeling (Vennix, 1996; Richardson, Andersen and Luna-Reyes, 2004; Richmond, 1997)

Yaffee (1999) describes a range of approaches, ending with one idealized form, ecoregional management, that involves restoring and maintaining ecosystem function while allowing sustainable human uses, with "the ecosystem as an integrated spatial unit, fitting within a nested hierarchy of geographic units; ...collaborative decision making decentralized to the ecoregion level;...reorganization of management along ecoregional lines." While he cautions that "one of first steps in collaborative decision making...the development of a shared definition of the problem", this formulation is actually very familiar to coastal managers.

Emerging coastal ecosystem management: a case in progress

Rhode Island is one of the first states (1971) to adopt a coastal management law creating a program that engages in direct state regulation of marine and coastal resources, predating the federal law by a year. The state's Coastal Resources Management Council, was created to perform a balancing act.

> It shall be the policy of this state to preserve, protect, develop, and, where possible, restore the coastal resources of the state for this and succeeding generations through comprehensive and coordinated long range planning and management designed to produce the maximum benefit for society from these coastal resources; and that preservation and restoration of ecological systems shall be the primary guiding principle upon which environmental alteration of coastal resources will be measured, judged, and regulated. (General Laws of Rhode Island, § 46-23-1)

In 2004, the Rhode Island General Assembly called for the preparation of a Marine Resources Development Plan:

> To provide an integrated strategy for a) improving the health and functionality of Rhode Island's marine ecosystem; b) providing for appropriate marine-related economic development; and c) promoting the use and enjoyment of Rhode Island's marine resources by the people of the state. [Rhode Island Senate Bill S-3028A, signed June 30, 2004]

This is an early state response to the action recommendations of the U.S. Commission on Oceans and provides the opportunity to reframe coastal management from a largely regulatory approach dating from the 1970s emphasize on gaining control over uses, toward an eco-regional approach.

The working group assembled to assist the Coastal Resources Management Council in preparing the plan is reflecting on both the 35 year experience in Rhode Island, which calls itself the "Ocean State", and placing this in the much larger context of the state's interaction and dependence on the marine and coastal environment since the post-Civil war era.

Rhode Island's industrialization and urban development phase lasted through World War II, with the city of Providence and the urban core growing rapidly. The post war economy changed, as did development patterns, leading to a decline in manufacturing, the loss of population in the central city and the rise of the suburbs. Along with this was growing concern for water pollution, land and shore development, leading Rhode Island to develop pollution control plans early on, as well as become a leader in coastal management. By the 1990s the results of these investments have paid off, with much of the shoreline conserved, water quality restored and an effective regulatory program in place. (Rhode Island Department of Environmental Management, 2000) The decisions reflect a continuing balancing act during periods of high unemployment, when pressure to ease up restrictions might be been high, and episodes of environmental disruption, such as an accidental sewage spill or a late summer fish kill, that generates pressure to clamp down further. Finally, the State's economy and population is changing in structure and character, so that the coastal resource use allocations that were put into law in 1983 may not be adequate as the state looks ahead.

Most of Rhode Island is part of the larger Boston metropolitan area, which is also exerting demand over the state's land, shore and marine water. We know from experience that a marine ecosystem and the characteristics of coastal communities can shift, or "flip" into more or less desirable configurations. Narragansett Bay and the state's coastal lagoon systems have, in the past, and could, in the future, change their level of productivity and what they produce. This is a central concept in the ecosystem management literature as well. (Walker, et. al., 2002) We would like to be able to design the future of our Social-Ecological System (SES), but we do not yet have a consensus on the need to act, what future we would like, and what we need to do to both avoid undesirable conditions and move closer to desired ones. But we do not have the tools that the advocates of managing for resilience recommend, nor the confidence that we can employ them. The facts about how much progress has been made are not well know, indeed the lag in public understanding and perception of these advances can probably be measured in terms of a decade, not years. This could be a major obstacle in stakeholder discussions.

Using an SD approach to guide inquiry on the future of coastal ecosystem management

To gain some clarity on what coastal ecosystem management entails, the Rhode Island coastal management program's legislative purpose is used to create a simple dynamic model of the balancing act involved in allocating coastal resources, called "sites" for simplicity. In this model, coastal management involves nothing more than deciding what sites in the coast are to be

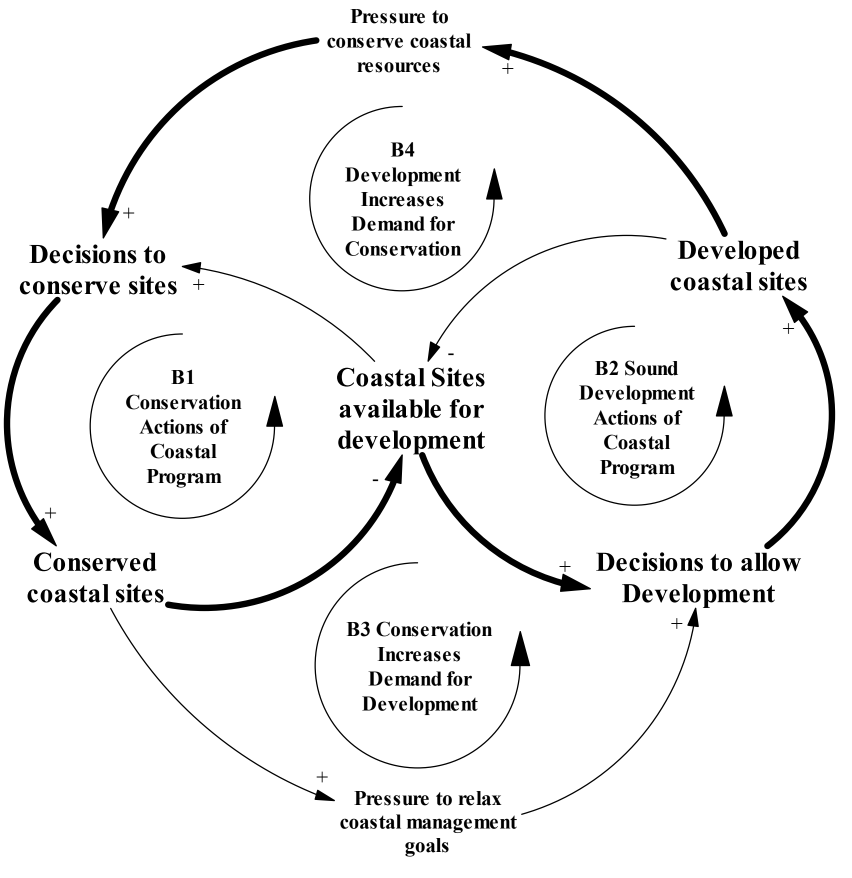


Figure 1: A causal loop depiction of the simple coastal ecosystem management model

developed and which are to be preserved. A coastal site could be a beach, wetland, lagoon, tidal flat, sand dune, bluff, or a parcel of dry, buildable land. One of many key simplifications is that technology and money can produce some kind of development from any available sites.

There are four important loops at work in this simple coastal ecosystem management world, shown in Figure 1. In balancing loop B1, pressure to conserve coastal resources leads coastal decision-makers, whomever they might be, to remove sites from the inventory of available sites. In balancing loop B2, the decision makers allow certain sites to be developed under a set of stipulations. Both conservation and development reduce the stock of available sites. This sets two additional dynamics into motion. As development takes place, the coastal area's economy grows, demand for sites increases, and the increasing scarcity of those sites is noticed, generating pressure to relax conservation policies and allow more sites to be developed, shown in balancing loop B3. Similarly, any increase in development, combined with the perception of declining availability of sites, generates pressure on the coastal management decision makers to conserve more sites, shown as balancing loop B4. This in stark form is the classic balancing act embodied in Rhode Island's 1971 coastal management law and program.

What can we ask such a simple conceptual model that might offer some insight into the ongoing challenges of managing a real coastal ecosystem and help prompt reflection on experience to date? Brunner and Clark [1997] emphasize that ecosystem managers "are not omniscient, these and other practitioners must make interpretations and judgments that function as maps for self-orientation in the decision context...When practitioners act on such maps, the consequences of their actions unfold in a much more complex world that provides a reality check." In their view, "the priority is to evolve improvements in principles of ecosystem management through reflection on the experience that follows action".

One question derived from real world experience in Rhode Island is whether planning matters. Concepts such as adaptive ecosystem management seem to eschew any kind of pre-planning. In fact, not all researchers agree that the ecological concept of resilience, which refers to self-organizing systems, applies equally to a system with significant engineering-designed components like most SES. The concept of *robustness* has been proposed as more useful in characterizing how their productivity and flow of services are being maintained despite disturbances, since "the majority of components are self organizing (ecological systems, social networks), very few are designed (rules of interaction), and uncertainty is high". [Anderies, Jannsen and Ostrom, 2004] At a minimum, six elements of an SES have to be taken into account in ecosystem management :

the natural resource;
the resource users;
the public infrastructure providers (public decision makers);
the public infrastructure itself;
institutional rules; and
the external environment.

Strategic interactions take place among these entities. The robustness of a particular social-ecological system must take into account both the collective choice making and operational (implementation) aspects.

The stock and flow model that derives from the conceptual model can accommodate these recommendations.

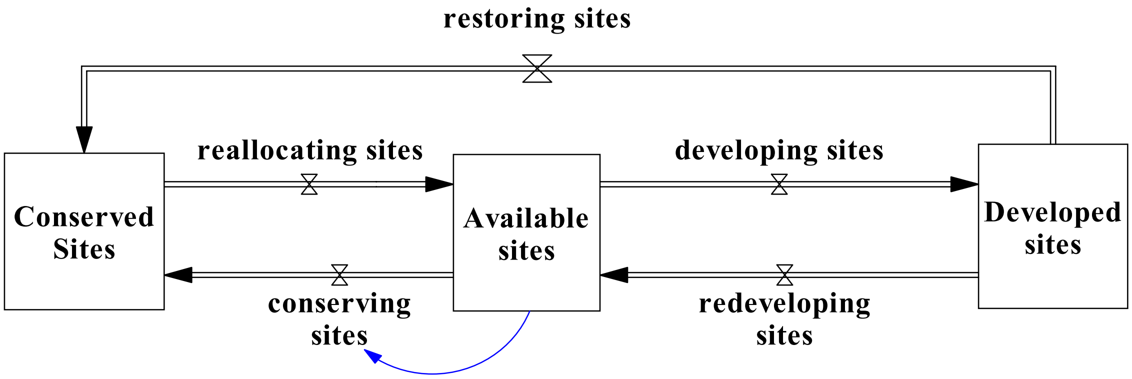


Figure 2: The stock and flow structure of the simple coastal ecosystem management model

The model consists of three main stocks and five processes that represent what can happen to a site at different times, reflecting the real world decisions of coastal management. Initially, all sites are available, and coastal decision-makers can decide to permit them to be (1) developed or (2) conserved. Over time, developed sites might be (3) redeveloped, or in rare cases (4) rehabilitated so they can be conserved. Finally, conserved sites can be (5) reallocated into the pool available for development. The decision-maker is not specified in the simple model, it could represent the result of an arbitrary decision by a local, state or federal authority, a collective choice process in the case of implementing a plan, or the private negotiation of property owners.

A simple example for a pristine, undeveloped coastal beach site illustrates the different possible stocks where the site could be located in the world of the model.

SITE DECISION	EXAMPLE
(1) Developed	A wharf is constructed in an existing small harbor along with offloading equipment, fish processing and cold storage facilities to meet the needs of near-shore fishing operations.
(2) Conserved	A government agency declares that no structures or physical modifications such as dredging are allowed to a specific coastal salt marsh located in the innermost portion of the harbor.
(3) Restored	A hurricane storm surge generates severe beach erosion on the barrier beach of a coastal lagoon. Sand that washed into the lagoon is returned to nourish and reestablish the damaged beach.
(4) Redeveloped	An obsolete and abandoned fuel off-loading and storage facility in the small harbor is removed and remediated and redeveloped as a time-share condominium with the option of a boat slip.
(5) Reallocated	A state agency obtains a large parcel of undeveloped land adjacent to a popular recreational beach which had previously been set aside for conservation. The agency establishes a new public beach facility with 500 parking spaces, a large pavilion with concessions, lockers and showers, and life guard stations.

Table 1 Decisions that can affect which stock contains the site

The working model described below moves a site between stocks 1, 2, 3 and 5. A separate stock uses information from (1) Developed level to track decisions to intensify existing uses of a site.

The model is very general and allows testing of a variety of parameters to create very different coastal ecosystem management situations, and to try out a range of coastal management policies. Elements of its structure draw upon the 'urban model" and the "project model", both of which are widely described in the SD literature (see for example the classic treatments in Richardson and Pugh, 1989) and used in many introductory courses.

COASTAL SITUATION PARAMETER	MEANING
1950 demand for coastal sites	This sets the initial demand rate per person for coastal sites. The model start year can of course be changed
Initial population	This sets the population at the beginning of the model run
Total sites	This sets the number of sites remaining to be developed
Pre-existing developed sites	Any coast with population will have sites already utilized. This parameter is added to the 'cumulative decisions allowing development of sites" so that site intensification decisions can be computed
Net census population growth rate	We can change how fast the population of the model world grows by a fraction. The parameter is phrased this way because in the Rhode Island case, managers believe that official census data undercounts the number of people living on a temporary or permanent basis in coastal municipalities.
Net extra population growth rate	This allows the model to account for growth in the number of people not counted by the census
Year to test extra population	This allows for choosing a time period in which non-census population increases
normal demand for intensifying sites	This parameter sets a rate of requests for permits to intensify use of a site per existing developed site
normal restoration fraction	this parameter allows for aging structures to be demolished and returned to the available sites stock
Long term growth in median income	This parameter allows for prosperity in the world of the model, and increases the 1950 demand for coastal sites

The policy test variables are also general, but their selection very much reflects the history of the Rhode Island coastal resources management program.

POLICY TEST VARIABLE	MEANING
conservation goal	The model run can attempt to set aside from 0 to 100 per cent of remaining available sites through case by case decisions
initial conservation year	the time to begin the conservation policy can be set
initial plan allocation policy	The model run can attempt to set aside from 0 to 100 per cent of remaining available sites by declaring them conserved in a plan. We can decide to conserve a large quantity of sites all at once, setting the initial year for implementation, and allocating the number of sites to conserved.
initial plan year	the time to implement the plan can be chosen
Year to implement the site decision program	this sets the time when a coastal program will begin to implement the permit system
Year to implement site intensity decision policies	This allows for the application of regulatory review of activities that change the intensity of use of sites that have already been developed
Rate of enforcement	This is a fraction applied to conserved sites that can return them to the status of sites available for development
Time to reallocate sites due to enforcement	This smoothes the return of conserved sites to available status

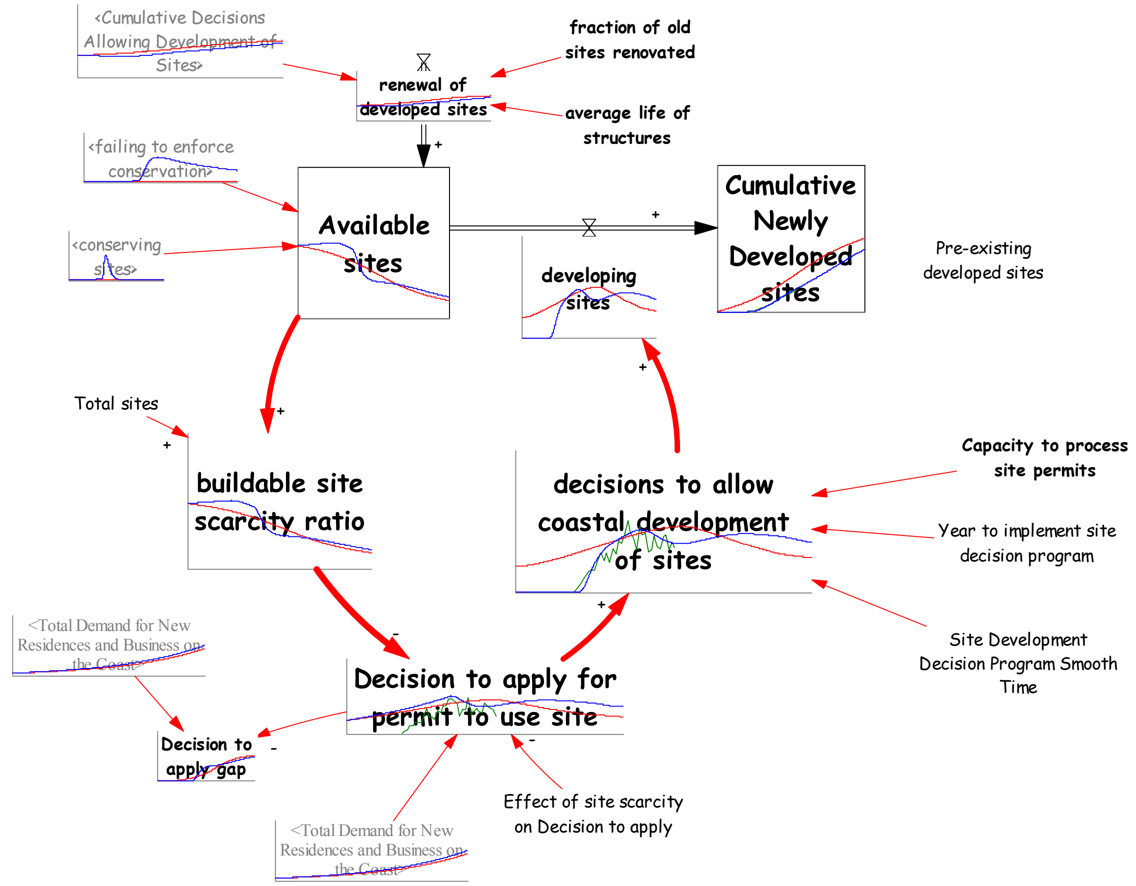


Figure 3 Developing Sites

The main equations for the balancing loop that develops sites are:

Available sites= INTEG (+failing to enforce conservation-conserving sites-developing sites+renewal of developed sites)
buildable site scarcity ratio=Available sites/Total sites
Decision to apply for permit to use site=Effect of site scarcity on Decision to apply(buildable site scarcity ratio)*Total Demand for New Residences and Business on the Coast
Decision to apply gap=(Total Demand for New Residences and Business on the Coast-Decision to apply for permit to use site)/Total Demand for New Residences and Business on the Coast
decisions to allow coastal development of sites=SMOOTH3((Decision to apply for permit to use site*Capacity to process site permits)*(STEP(1, Year to implement site decision program)) ,Site Development Decision Program Smooth Time)
Decision to apply for permit to use site=Effect of site scarcity on Decision to apply(buildable site scarcity ratio)*Total Demand for New Residences and Business on the Coast

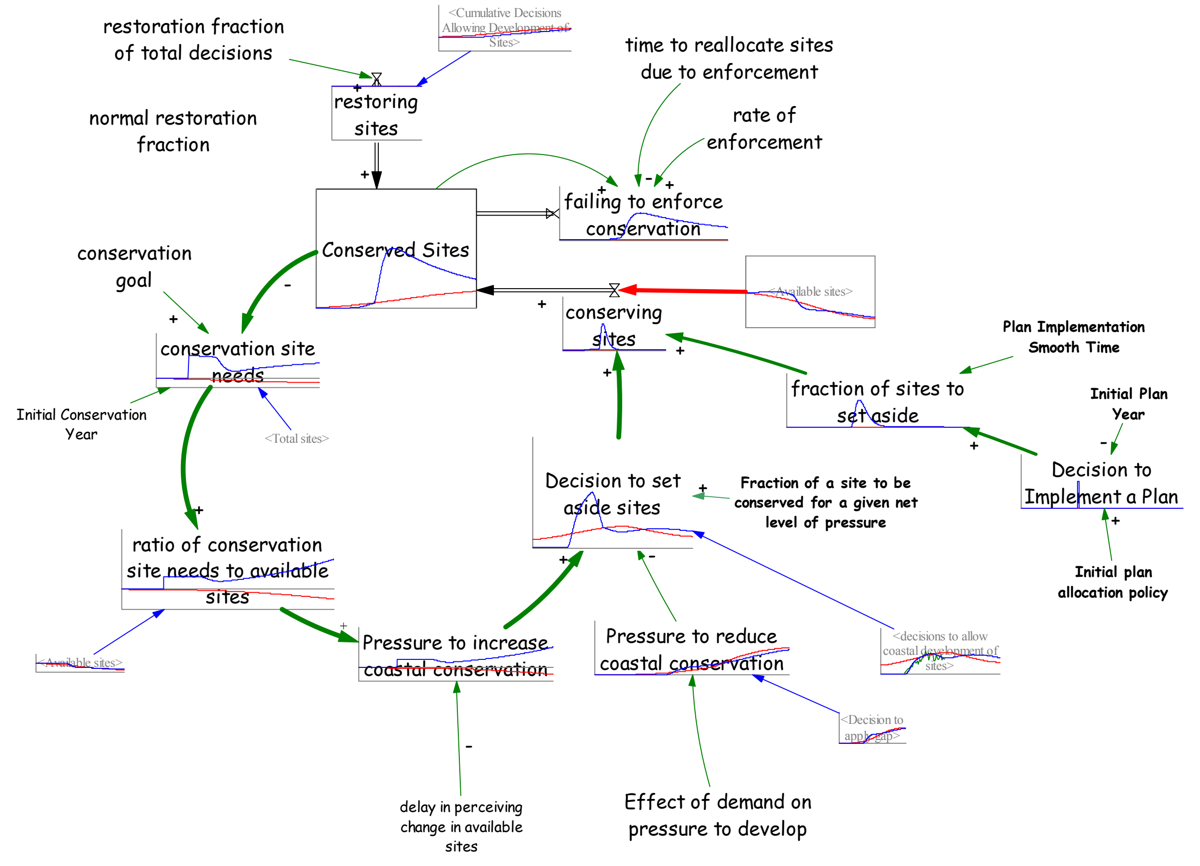


Figure 4 Conserving Sites

The main equations for the balancing loop that conserves sites are:

Conserved Sites= INTEG (conserving sites+restoring sites-failing to enforce conservation, 0)
conservation site needs= (STEP(1, Initial Conservation Year)*conservation goal*Total sites)-Conserved Sites
conserving sites=(fraction of sites to set aside*Available sites+Decision to set aside sites)
Decision to Implement a Plan=PULSE(Initial Plan Year, 1)*Initial plan allocation policy
Decision to set aside sites=Fraction of a site to be conserved for a given net level of pressure(Pressure to increase coastal conservation - Pressure to reduce coastal conservation)*decisions to allow coastal development of sites
fraction of sites to set aside=SMOOTH3(Decision to Implement a Plan ,Plan Implementation Smooth Time)
Pressure to increase coastal conservation=ratio of conservation site needs to available sites/delay in perceiving change in available sites
Pressure to reduce coastal conservation=Effect of demand on pressure to develop(Decision to apply gap)
failing to enforce conservation=((1-rate of enforcement)/time to reallocate sites due to enforcement)*Conserved Sites

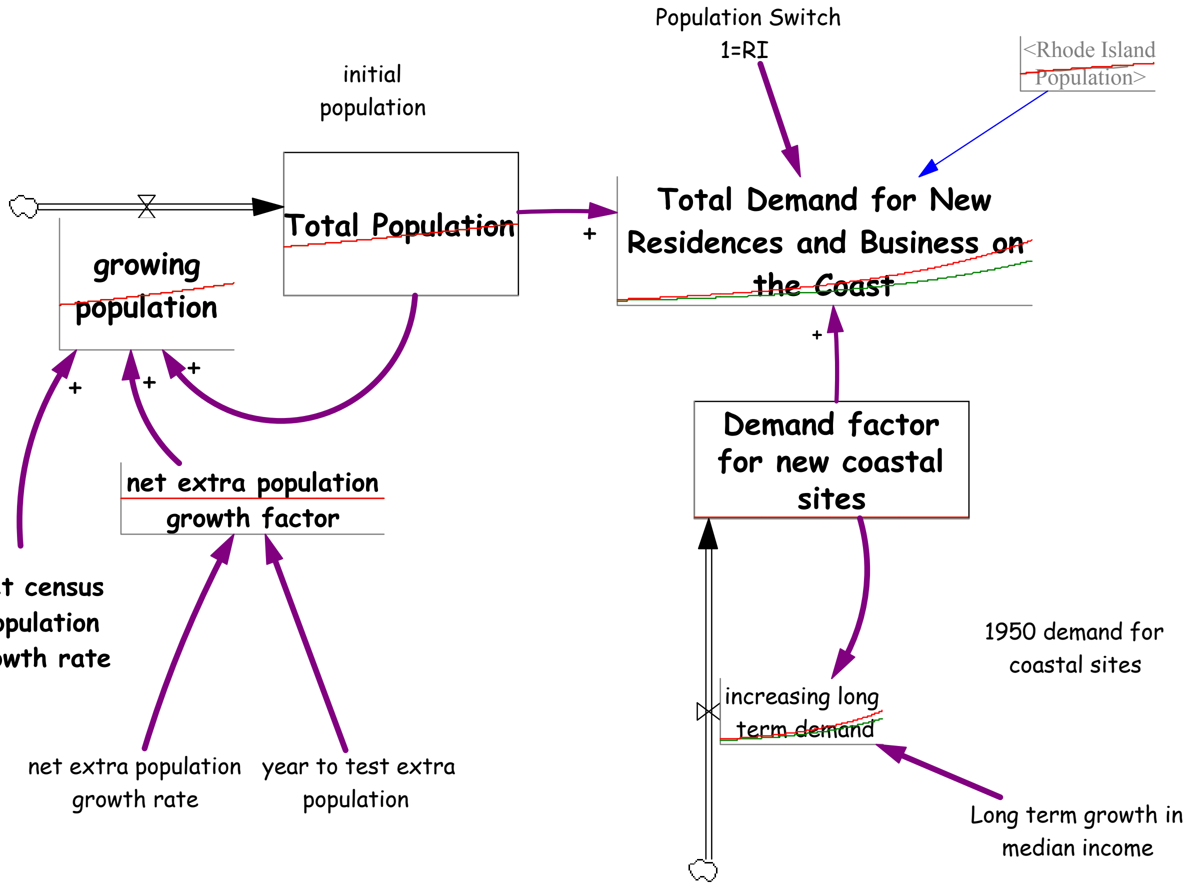


Figure 5 Population and economy components

The main equations for population growth and demand for new sites:

Demand factor for new coastal sites= INTEG (increasing long term demand,"1950 demand for coastal sites")
growing population=(net census population growth rate+net extra population growth factor)*Total Population
increasing long term demand=Long term growth in median income*Demand factor for new coastal sites
Total Population= INTEG (growing population, initial population)
Total Demand for New Residences and Business on the Coast=Demand factor for new coastal sites*(((1-"Population Switch 1=RI ")*Total Population)+(Rhode Island Population*"Population Switch 1=RI "))

To maintain simplicity, this component of the model acts exogenously at present, however a common sense view would be that the condition and attractiveness of coastal ecosystems would have an effect on property values and in-migration. This is accounted for in some way by the "net extra population" variable, which has to be set as a parameter rather than a feedback loop.

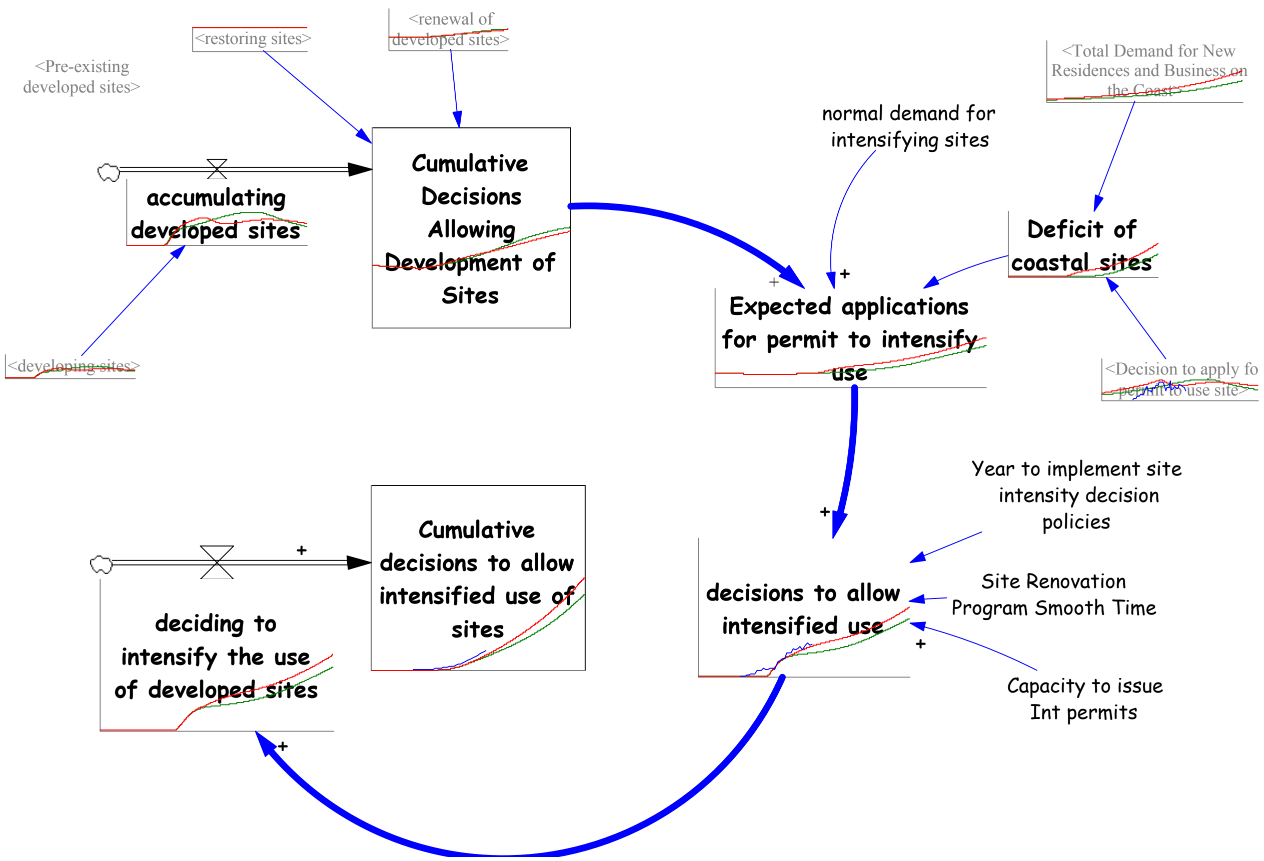


Figure 6 Intensifying use of sites

The main equations for intensifying use of sites are based mainly on normal demand for intensification, plus pressure from the deficit of coastal sites. This component is also somewhat isolated from the rest of the model, and serves mainly to model the coastal decision maker's work load without itself generating feedback into the economic or population models, for example.

Cumulative Decisions Allowing Development of Sites= INTEG (accumulating developed sites-renewal of developed sites-restoring sites,"Pre-existing developed sites")

Cumulative decisions to allow intensified use of sites= INTEG (deciding to intensify the use of developed sites, 0)

decisions to allow coastal development of sites=SMOOTH3((Decision to apply for permit to use site*Capacity to process site permits)*(STEP(1, Year to implement site decision program)) ,Site Development Decision Program Smooth Time)

Deficit of coastal sites=(Total Demand for New Residences and Business on the Coast-Decision to apply for permit to use site)

Expected applications for permit to intensify use=(Deficit of coastal sites+(normal demand for intensifying sites*Cumulative Decisions Allowing Development of Sites))

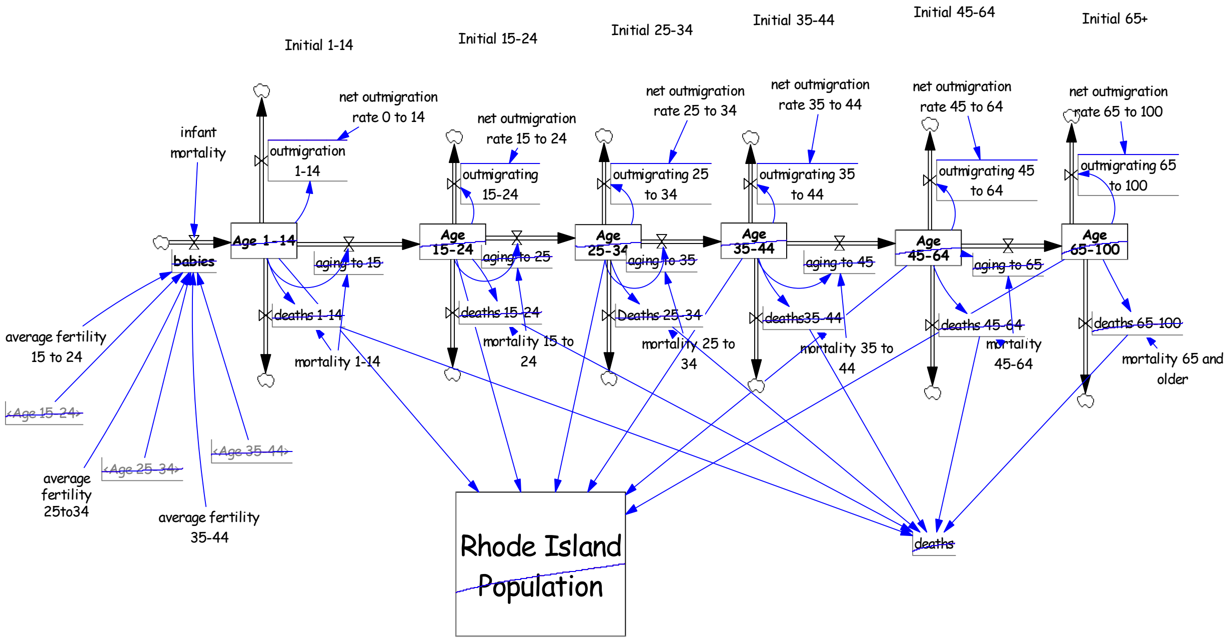


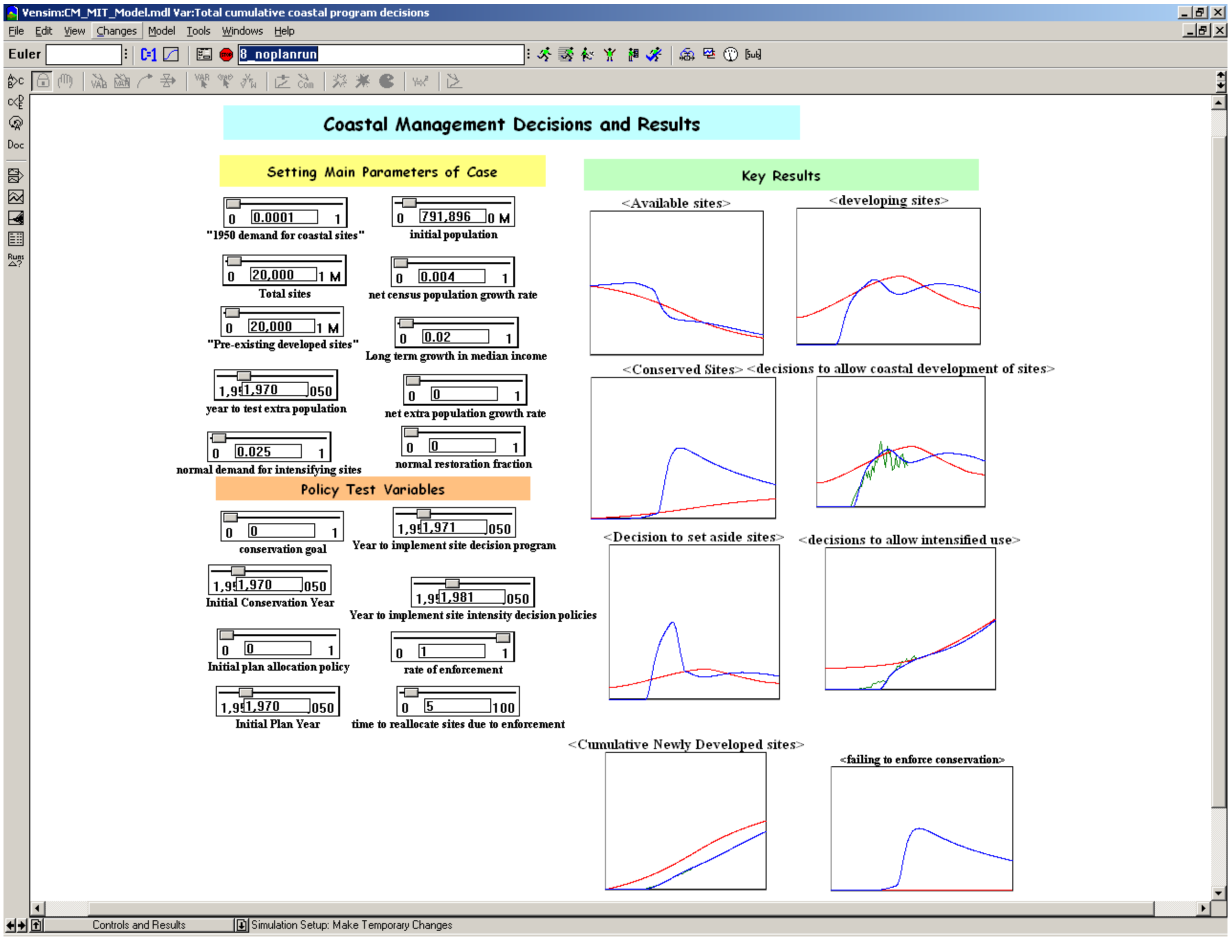
Figure 7 Population submodel

The population submodel is switched off in the runs shown below, but is of interest to the coastal management program.
The main equation for a population cohort is

"Age 25-34"= INTEG (aging to 25-aging to 35-outmigrating 25 to 34-"Deaths 25-34", "Initial 25-34")

babies= ((("Age 15-24"/2)*average fertility 15 to 24)+(("Age 25-34"/2)*average fertility 25to34)+(("Age 35-44"/2)*"average fertility 35-44"))*(1-infant mortality)

Selected parameters and policy variables are combined in a screen that allows immediate viewing of parameter results.



Setting Main Parameters of Case

0 0.0001 1
"1950 demand for coastal sites"

0 791,896 0 M
initial population

0 20,000 1 M
Total sites

0 0.004 1
net census population growth rate

0 20,000 1 M
"Pre-existing developed sites"

0 0.02 1
Long term growth in median income

1,95 1,970 050
year to test extra population

0 0 1
net extra population growth rate

0 0.025 1
normal demand for intensifying sites

0 0 1
normal restoration fraction

Policy Test Variables

0 0 1
conservation goal

1,95 1,971 050
Year to implement site decision program

1,95 1,970 050
Initial Conservation Year

1,95 1,981 050
Year to implement site intensity decision policies

0 0 1
Initial plan allocation policy

0 1 1
rate of enforcement

1,95 1,970 050
Initial Plan Year

0 5 100
time to reallocate sites due to enforcement

Figure 8 Interface for setting case parameters and policy tests

Model Runs

Two runs are presented here, the first serves as a baseline by using parameters from Rhode Island case without coastal management, and the second tests the results of a conservation policy backed by a conservation plan.

As background, the model outputs are inspired by two key coastal use decisions in the Rhode Island program. First, the program can decide whether available coastal sites can be used (uses sites, red line) and whether a used site can be further modified or rehabilitated (Rehabs existing, blue line). Figure 9 presents annual data from actual program experience, and Figure 10 shows cumulative data.

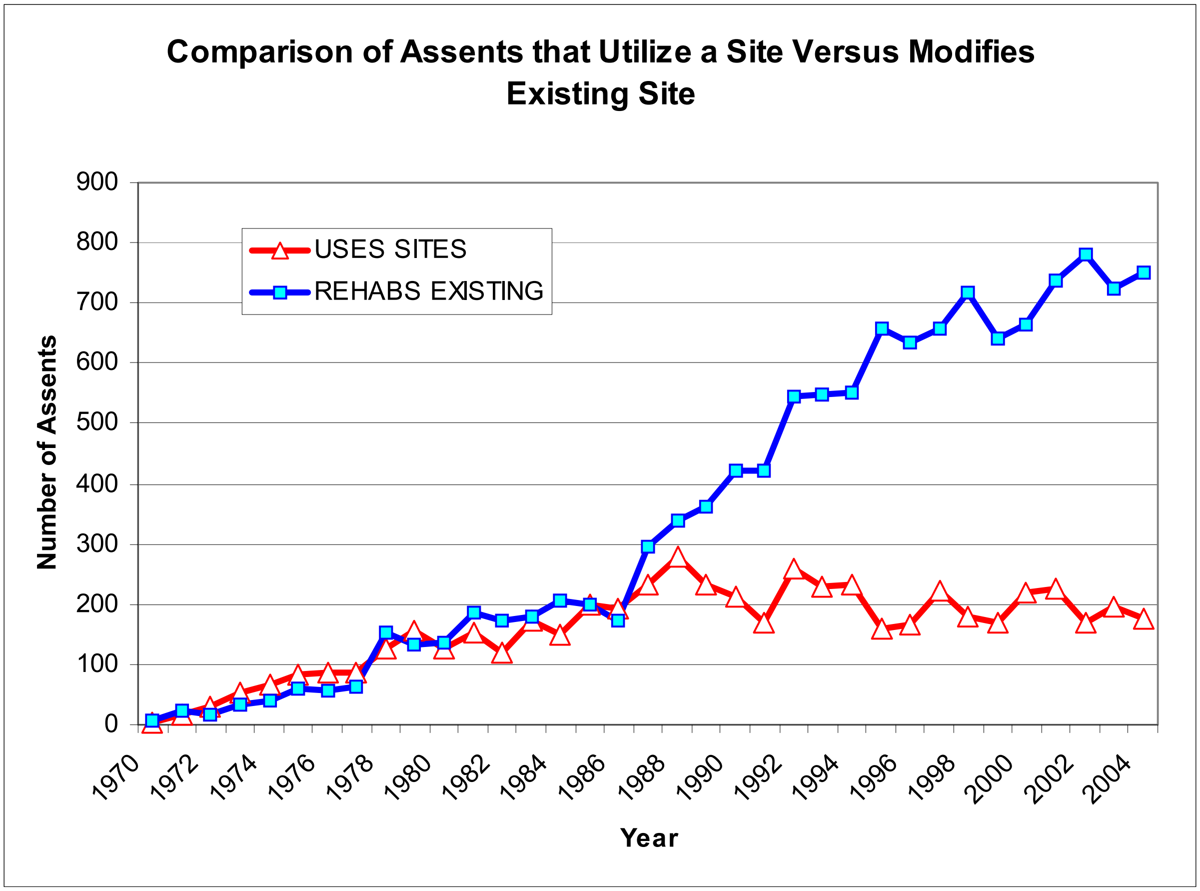


Figure 9 Annual decisions (assents) to use and rehabilitate sites in Rhode Island (data from CRMC Permit Decision Data Base)

In general, we will be looking to see if the model is able to generate similar results when reasonable parameters taken from the Rhode Island case are used.

The following kinds of projects are related to decisions to use available sites:

Aquaculture/Water Based
Commercial Structure
Docks Piers Floats Commercial
Docks Piers Floats Residential
Dwelling/ISDS
Dwelling/Sewered
Filling Removing Grading
Industrial
Marinas New
Mosquito ditches
Petroleum/chemical
Power and Energy
Private Recreation Structure
Public Recreation Structure
Shoreline Protection New

The following kinds of activities are related to rehabilitating or intensifying a coastal site:

Accessory structure
Buffer zone alteration
Commercial Alteration
Dredging Improvements
Dredging Maintenance
Dwelling Additions
Dwelling Alteration
Fuel tanks
Industrial Alteration
ISDS Repairs
Landscaping
Maintenance of Docks, Piers, Floats
Maintenance of Residential/Commercial/Recreation
Marinas Alterations
Non Structural Shore Protect
Right of Way improvements
Shoreline Protection Repair

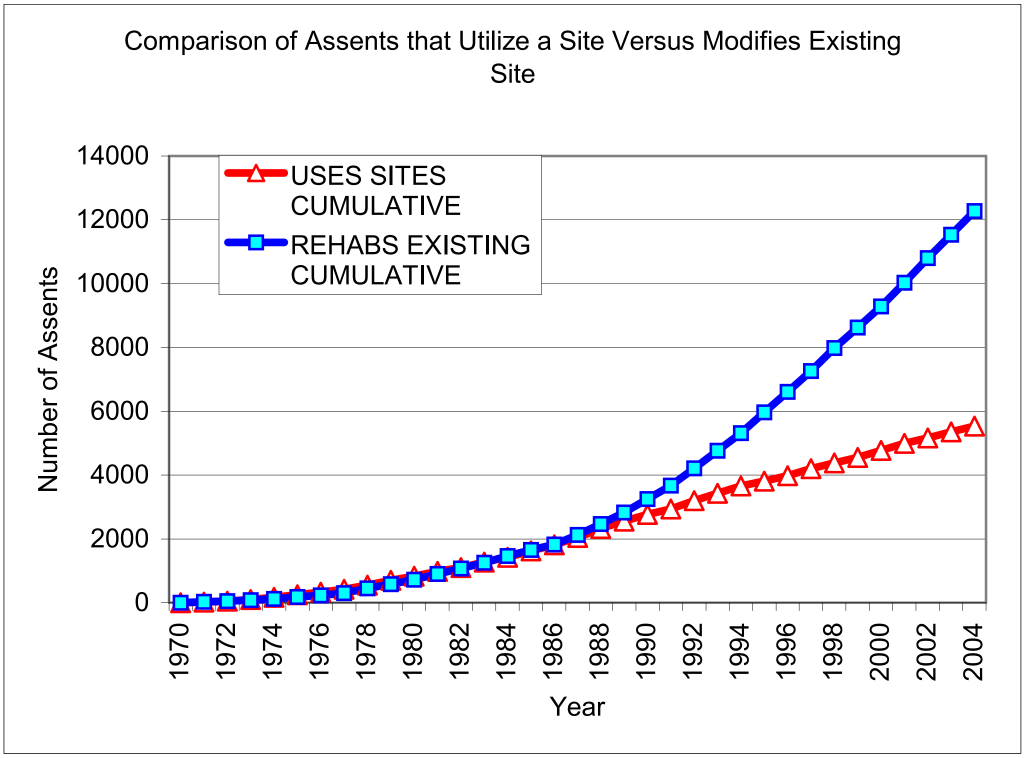
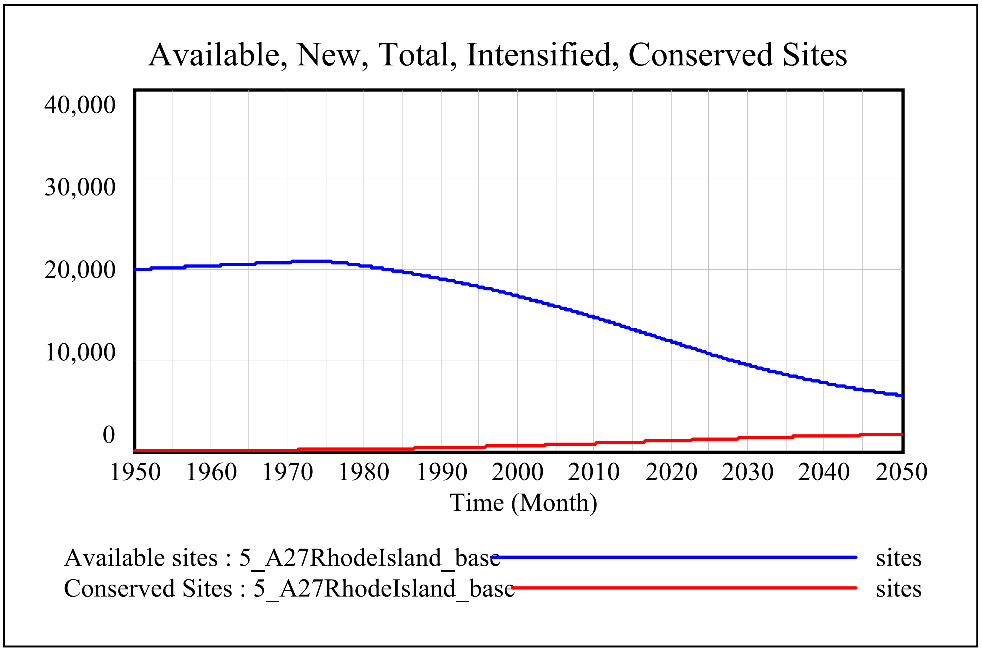


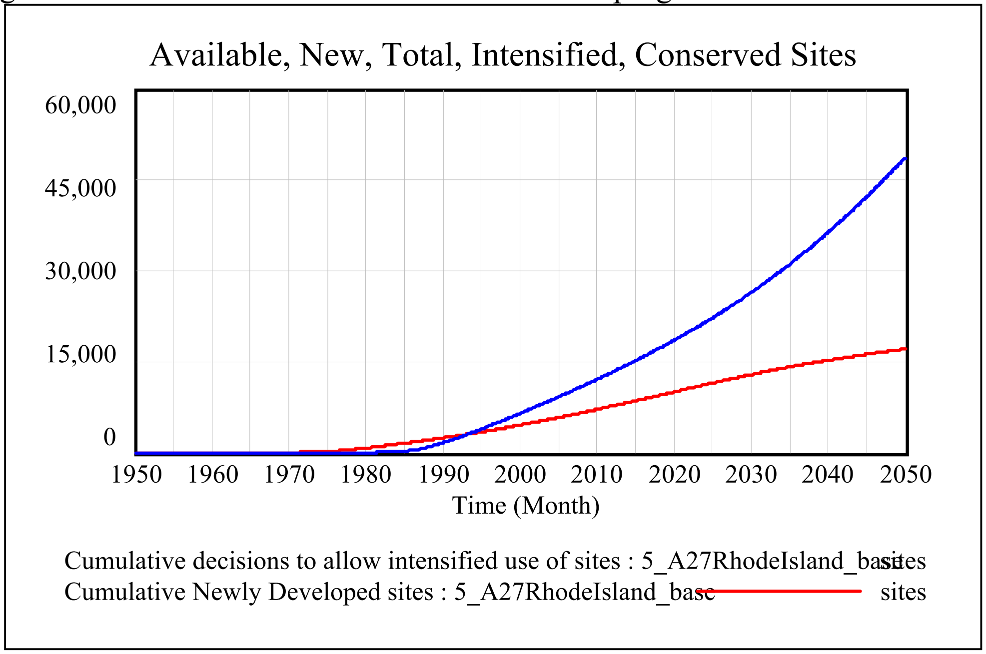
Figure 10 Rhode Island cumulative decisions on using new sites and rehabilitating existing ones

Base Rhode Island Model Run: No Conservation Policies or Coastal Plans
Parameters
The base run uses these parameters: Sites= 20000; Existing Developed Sites= 20000. There is also a base assumption that 0.1 sites is conserved for every site developed, that base demand for sites in 1950 is 113 sites/million people/year, and that the 1950 Population= 791896

Model results
In Figure 11, the number of available sites drops considerable over the model run, and a small fraction of sites is conserved due to the minimum assumptions of the run.



In Figure 12, the accumulation of new sites and intensified sites has the same shape, but much higher levels than the data from the Rhode Island program.



Plan Implementation Runs:

Model result
A plan that sets aside a fraction of sites early on is much more effect than a policy that is initiated later on in the development process, when sites are scarcer and pressure to develop more acute. This model run shows the results of both planning and case by case decision making.

The parameters tested are for the Rhode Island case:

Goal is to conserve 50 per cent of sites, Program begins in 1971
Plan is to conserve 50 per cent of sites,Plan implemented in 1985
Policies to control site intensification becomes effective in 1981
Base demand is for 113 sites/million people/year
Enforcement effectiveness is 90%
Permitting efficiency is 90%

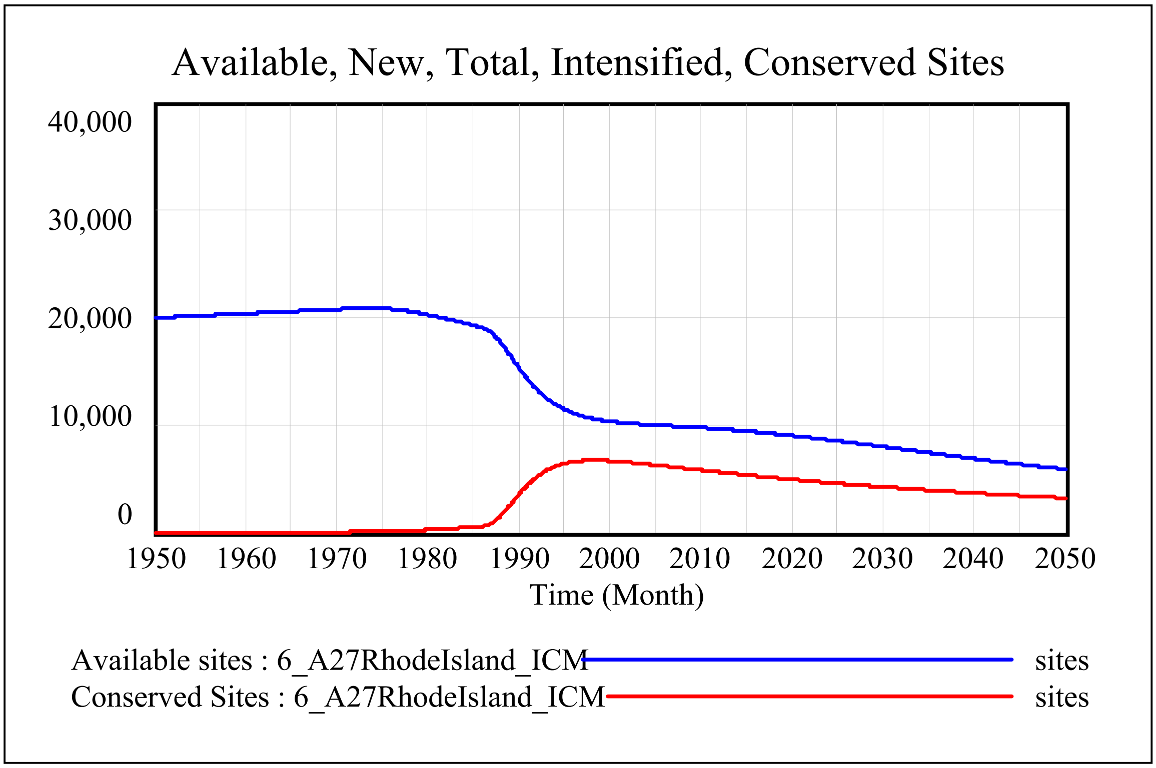


Figure 13 shows the result of implementing the plan and backing it up with case by case decisions. The amount of available sites is reduced, and the amount of conserved sites increases. Remaining available sites decline more slowly than in the base run, but conserved sites also decline due to weak enforcement. In practice enforcement issues probably do not have such a dramatic effect, so the parameter needs to be revisited.

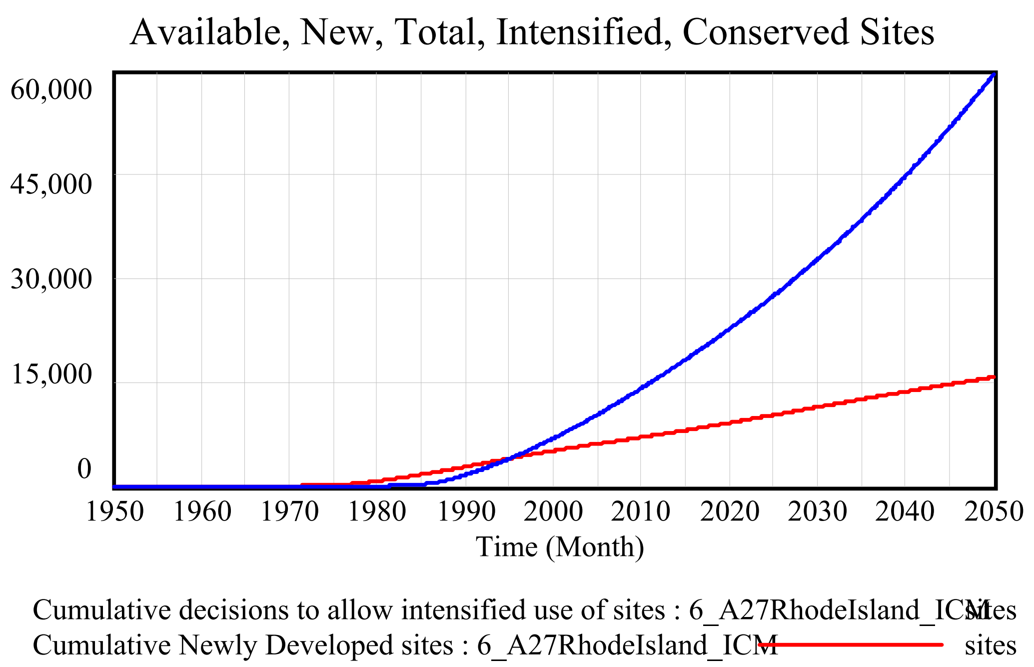


Figure 14

Figure 14 shows the cumulative results. Fewer available sites are developed, but many more existing sites are subjected to intensified use. Figure 15 shows how a plan reduces the availability of sites. Line 2 (red) is the model result without coastal management. Line 3 (blue) shows the effect of implementing a plan.

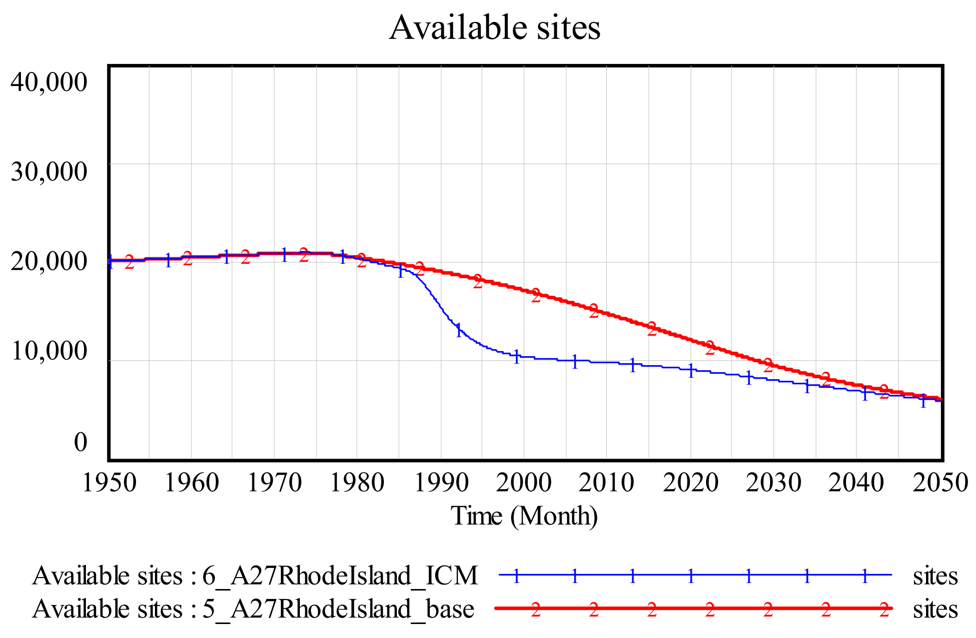


Figure 15

Comparison to Data from the Rhode Island Coastal Program

Figure 16 shows the actual data from the Rhode Island coastal program between 1970 and 2004 compared to the base and plan test runs. The annual decision making data is noisy...the number of applications received each month varies considerably, as does the time it takes to process each of the kinds of site projects listed above. These factors could be included in another version of the model, allowing coastal managers to test different combinations of projects and utilize parameters on the time it take to issue permits in combination with bottlenecks generated by an overload of work, in order to address the regulatory efficiency question. The main point is that the simple model is able to reproduce the behavior of the program using guesses at how many sites remain to be developed and what the 1950 baseline was. The key fact is that the simple assumptions about demand for site, and the use of population and economic parameters drawn from Rhode Island historical trends combined with educated guesses goes a long way toward simple model validation.

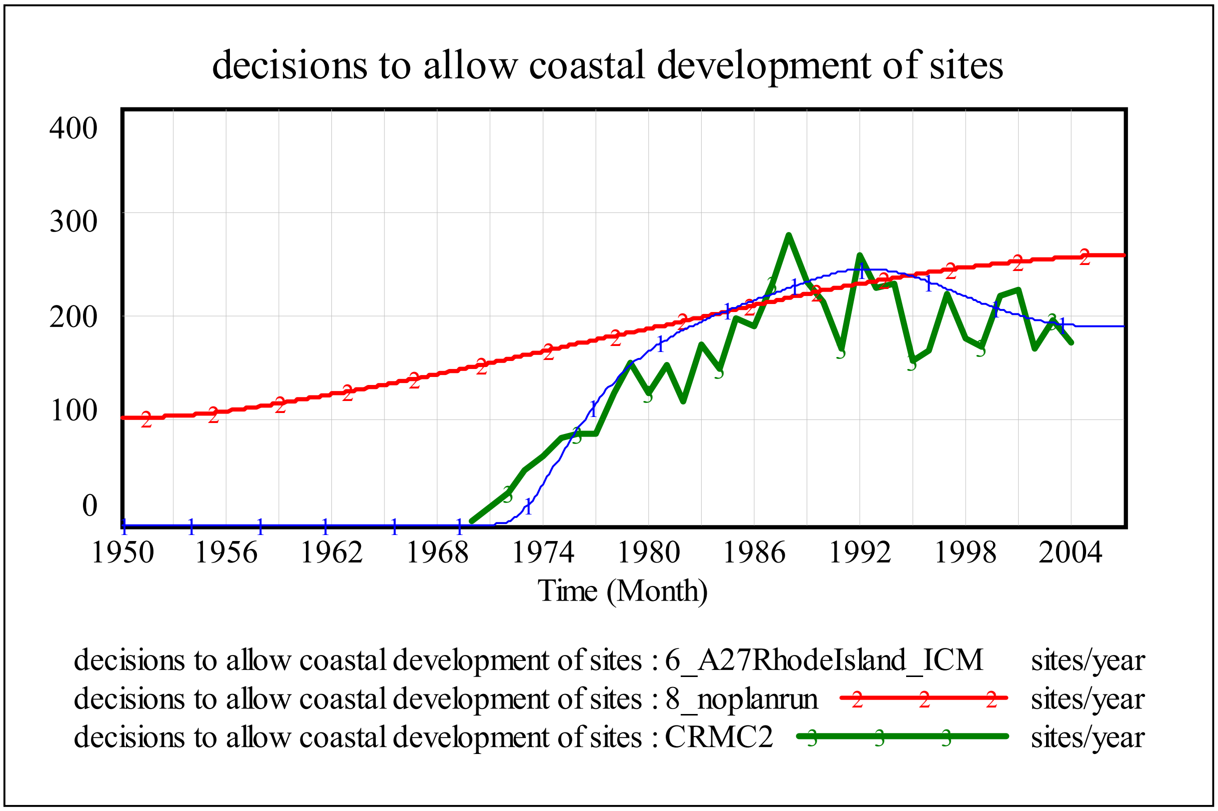


Figure 17 shows the results of matching actual Rhode Island data on decisions to intensify sites with model output. The model run with coastal management is shown in Line 1, blue color. Actual data is the thick green line labeled CRMC2. A similar story holds here. In fact, we do not know how many existing developed sites currently exist or how many remaining undeveloped sites there are. The graph shows actual data between 1970 and 1985 exhibiting a shallower slope than after 1985. In fact the coastal program did not have policies that would capture many of the site intensification actions until after 1985. A smoothing function and program start time of 1981 produces the model result. Some additional structure would be needed to better match the transition, but this perhaps would unnecessarily focus too much attention on modeling to the situation rather than validating the overall approach.

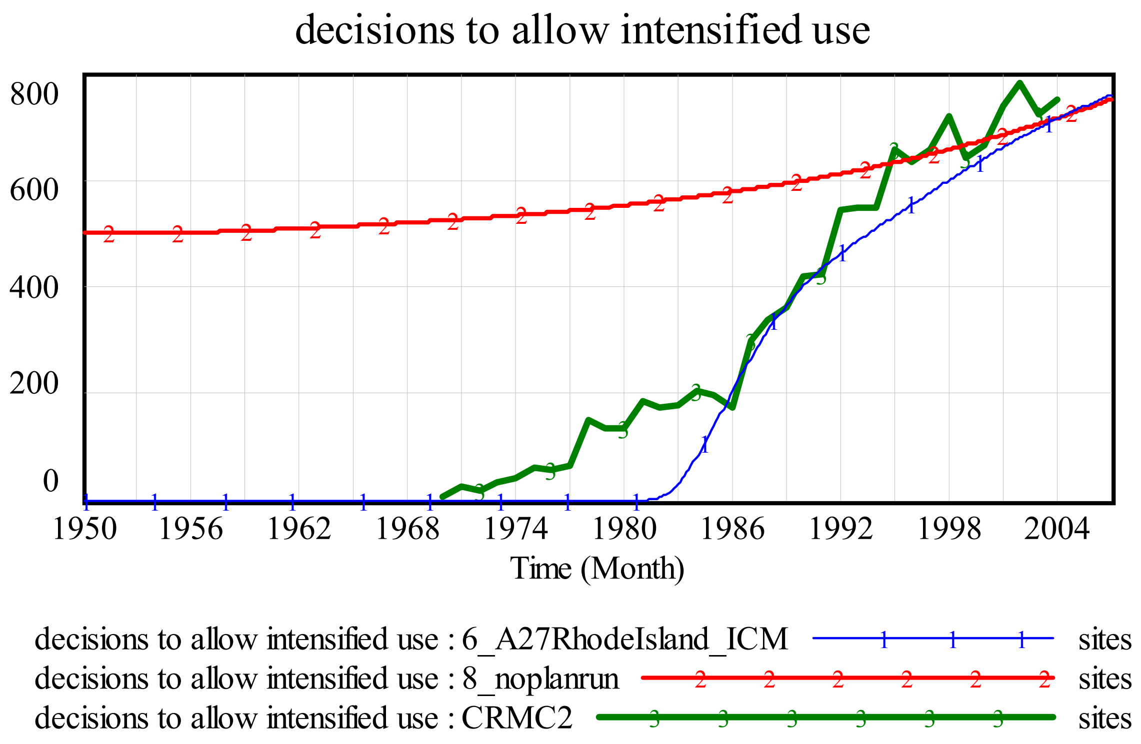
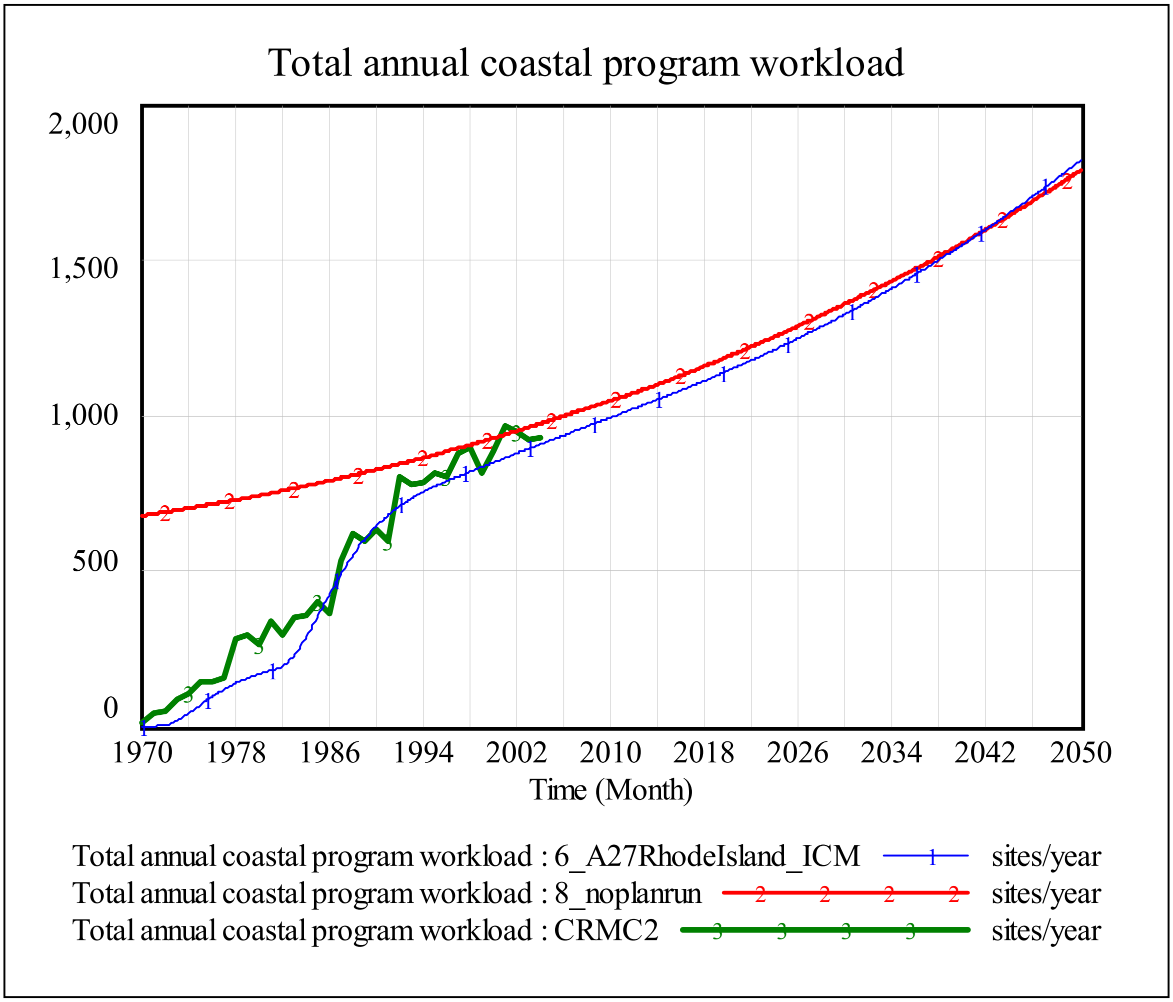


Figure 17

Combined together, the site and intensification of use graphs and data produce the graph in Figure 18, which is a projection of the total annual workload in the future using the parameters and assumptions in the model. The overall fit of the model run with coastal management (line 1, blue) to the actual data (thick green line, CRMC2) shows that the loops in the model act together to generate actual program behavior, thus merit further analysis and testing.

The main insight, however, is that the model forecasts an intensification in coastal program decision making due to the intensification of sites and the expectation that demand for remaining available new sites will stay steady. Decisions where the choice is between developing and setting aside a site for conservation are diminishing in number. The emerging concern of the Marine Resources Development Plan is how to take a design-oriented approach to creating coastal places. These are the small ports, seaside villages and redeveloping urban waterfront that are increasingly the focus of developers' attention as well as coastal municipality economic aspirations. The Coastal Resources Management Council is already reviewing its regulatory requirements for their suitability in more urbanized settings.



what can a simple model suggest for meeting the coastal management challenges of the 21st century?

Coastal management programs at the beginning of the process

In the simple world of the model, conservation policies remove land from the market place, and this puts further pressure to develop remaining sites. Plans help a great deal, but only if there is strong enforcement. Over the long run, sites will continue to be redeveloped, and as well some sites become obsolete, are destroyed and placed back into the Available Sites stock.

The simple model cannot say how many coastal sites need to be conserved in order for the people and the economy to be successful. Should it be 10,000 sites if the system contains 20,000? We cannot say. Nor does the simple model address the question of how “resilient” the remaining number of available sites plus conserved sites is. Its focus is mainly on WHETHER there will be any sites left. However, a resilience estimate component could be added, with feedback loops tied to both pressure to conserve in case by case negotiations, and in the fraction of the system to include when a system level plan is implemented. The coastal ecosystem may need to “flip” its configuration more than once before enough pressure is built up to motivate action and by then the list of potentially effective actions may change and get more expensive.

Finally, the simple model does not tell us about another key concern, which is the pollution generated from the development process. Conserving sites may create a buffer to pollution (the model does not address this) but a separate stock and set of processes is needed to identify and act on those factors, taking into account the same need for setting goals, maintaining pressure to implement, and addressing both the perception of the problem and signals that reveal when the pollution problem is solved. These ideas are equally valid for developed and developing coastal countries however many of the parameters in the simple model might need to take on very different values.

Coastal management programs at the mature stages of the process: intensification of use and cumulative impacts

The closer we become to build out in the world of the simple model, the fewer options we have and the less effective they are. It is never too late to implement a coastal conservation plan, however it can become too late to expect to get the same results as before. In a world with many fewer conserved sites, our expectations of what configurations are possible will have become reduced. Ecosystem management theorists recommend that we try to discover resilient pathways, since we cannot compute them. A mature situation seems to be more heavily dominated by human engineered components, and the notion of being able to design a desirable configuration seems entirely plausible, especially given the successes in resource conservation and pollution control experienced in Rhode Island and many other U.S. states.

The simple model cannot answer our concerns about a specific configuration that is both desired and practicable but it offers us some additional processes that were not very important in the earlier stages but could make a difference now.

Even when the model is pushed to the extreme in a scenario with no planning or conservation goals some sites remain available for development in addition to the relatively few conserved sites that were negotiated at the beginning of the development process. In reality, there are many irregular, hard to develop sites that also have high conservation value. In addition, development will be driven toward those areas where higher densities are allowed, in other words, urban areas. Here, developed sites can be redeveloped or restored and conserved and trades can be made between strategically important conserved and available sites. In addition, if the model had a pollution creation and control component, it is easy to imagine additional tradeoffs that make new, previously unusable sites, available to the simple coastal model.

Carrying out these more complex assessments of conserved and developed sites is difficult to do for a large area. Rhode Island’s coastal sites, for example, include the following features:

FEATURE	ACRES	PERCENT
High Salt Marsh	2,708	0.413
Beaches	1,450	0.221
Rocky Shores	573	0.087
Tidal Flats	568	0.087
Low Salt Marsh	443	0.068
Brackish Marsh	427	0.065
High Scrub-Shrub Marsh	159	0.024
Eelgrass Beds	99	0.015
Pannes & Pools	46	0.007
Dunes	43	0.007
Artificial Jetties & Breakwaters	23	0.004
Oyster Reefs	9	0.001
Stream Beds	3	0.001

Source: RI Department of Environmental Management, 2000.

These features are scattered throughout the coastline in many different sites. In addition, the Rhode Island Coastal Resources Management Council has afforded protection to five main types of coastal areas in addition to open water. Each of these areas might include several of the coastal environmental features listed above, but the polygons are too small to be the subject of a useful mini-modeling exercise to determine resilience and create a set of policies that will be robust. For example, it might make sense to reallocate industrial waterfront to commercial or recreational use. However, it may not make economic sense to expect that investors based in Providence, at the head of Narragansett Bay, would become involved in developing commercial waterfront in Newport Harbor, at the mouth of the bay, which has a very different market niche and a far more intense role as a seasonal tourism attraction.

One alternative approach that has already proven highly successful in the U.S. (Goss, 2003; NOAA, 1999), and especially in Rhode Island, is the use of special area plans. (Davis, 2004; Davis, Lopez and Finch, 2004) These are the equivalent of copies of the simple coastal world applied to a geographically and ecologically sensible subset of the available plus developed plus conserved sites. Rhode Island has adopted five such plans, and already revised three of them. (Dillingham, 1989; Imperial,1999; Imperial and Hennessey, 2000) Each special area zone is located in an ecologically sensible and contiguous area, for example the chain of coastal lagoons along the state's south shore, or Greenwich Bay, located in the mid-section of the encompassing Narragansett Bay. Most special area management zones contain many different coastal features, and multiple types of officially sanctioned uses, but have a common set of stakeholders willing to engage in an ecosystem planning process. Addressing competing demands for water area uses, and taking the experimental approach recommended in both *Beyond the Limits* and in the emerging ecosystem management literature can also be done more easily with strong stakeholder involvement at this more local scale focused on an identifiable coastal ecosystem.

Estimated allocation of uses for coastal and water areas in Rhode Island coastal zone:

DESIGNATED USE	TYPE CODE	PERCENT OF COASTAL AREAS
Conservation	1	0.27
Low intensity conservation and recreational use	2	0.57
High intensity recreation and marinas	3	0.04
Commercial and recreational waterfront	5	0.01
Industrial waterfront	6	0.10

Source: Rhode Island Geographic Information System, taken from the policies of the Rhode Island Coastal Resources Management Council.

How can the simple model help us ask questions and seek the right kind of information we need to better manage coastal social-ecological systems?

The model structure, its stocks, flows and auxiliary variables, gives us a simple but complete picture of what needs to be known to manage the model world. The model also allows us to estimate the effects of faulty perception of some of this picture. We can also track the results of decision making by using the model as a guide for collecting and analyzing available data. For example, while there have been only a few, infrequent studies of coastal land and water use in Rhode Island, the state coastal agency has a complete record of decisions it has made. Combining spatial data with decision trends data on specific kinds of development could be the basis for fairly fine tuned forecasting and scenario testing. Information on the location and other attributes of remaining sites would also prove invaluable in calibrating and further validating a somewhat more sophisticated version of the model.

Economy

The simple model has a single economic sector that has a single variable, and knowing its value is crucial to the model. Rhode Island's coastal economy has many sectors, remains dynamic and somewhat difficult to define precisely. Information is not currently available in a form useful for understanding current and future demand. One of the values of developed sites, particularly in the coast, is the tax revenue they generate from the very high property values found in most shore areas. Such data is available but not aggregated in a useable format.

Demography

The simple model has a single net growth variable, while the Rhode Island population shows S-shaped growth and is leveling off at about 1 to 1.1 million people. It has a growing deficit of working age residents and a rapidly increasing population of over-65. There are important coastal populations that are not included in demographic models and census data, including daily visitors and summer residents, college students who compete for rental housing with workers, owners of primary and second homes who have declared their primary resident elsewhere.

Pressures to conserve or develop

The simple model ties these pressures to perceptions of the rates or levels of key flows and stocks. The pressures involved in the balancing act carried out in the Rhode Island Coastal Program are generated from many sources and have their expression in case by case decisions, the overarching policies and regulations adopted to guide administrative decisions, and the ongoing process of creating and amending special area plans. The simple model can be extended to show the effect of public support and continuing involvement, but it would also have to show that as the conditions of the coast change (new configurations of available, developed and conserved sites) what the population wants from the coast is also likely to change, adjusting downward to an era of scarce sites, or upward in a scenario where sites are redeveloped, restored and reallocated. In either case, the increasing site scarcity and development pressure should mean than better deals can be negotiated with developers. However, Rhode Island is not collecting data that can be shared to provide state and local decision-makers with independent assessments of the value of remaining coastal sites to guide the negotiation process.

A Cap on Permits?

In an earlier version of the simple model, I tested a cap on the number permits processed per year to represent the effect of bureaucratic inefficiency as well as an intentional policy to reduce the pace of development. Lifting the cap, that is, creating a decision making system that has low transaction costs and few delays, does indeed let development happen faster, but as noted earlier, also has no long term benefit in the conservation of sites. Tightening the cap, to impose a moratorium on development in the model, actually delays conservation decisions as it creates increased opposition to conservation (which of course reduces the availability of sites further). Current discussions about the Rhode Island Coastal Program also urge improved regulatory efficiency, a need which extends well beyond the CRMC as an agency, which is seen as relatively efficient, however little is known about the true nature and cost of delays. A system modeling exercise would be a useful step in that direction.

Conclusion

The challenge facing the U.S. in coastal management in the next two to three decades is great, and that of the world's coastal countries greater and more urgent still. Until now, the more than three decades of world experience and writing on coastal management has drawn very little on the most basic of systems dynamics concepts despite being one of the most obvious arenas where dynamic complexity in its natural, social and governance dimensions. The SD field itself, by contrast has not neglected the environmental management challenge. (Ford, 1999; van den Belt 2004; Moxnes, 1998, 2004) The simple model presented here, drawn upon the statutory balancing of uses requirements of the Rhode Island coastal law, is able to incorporate a great many facets of the coastal management challenge and suggest fruitful areas of inquiry and extension, both in practice and for the model itself as a tool to educate and guide the emerging practice of coastal ecosystem management.

Acknowledgements

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