UNCERTAINTY, IRREVERSIBILITY, AND WATER PROJECT ASSESSMENT

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Most structural and some nonstructural water projects require significant sunk costs and lead to uncertain economic and ecological outcomes. For instance, building irrigation or flood control dam requires sizable sunk cost, an investment that is difficult to recover later. The dam faces uncertainties in terms of future rainfall, the performance of the dam's structures and downstream levees, the economic activities that affect the demand for irrigation water or flood control, and ecological impacts, particularly the society's valuation of these impacts. Some of these uncertainties are inherent and are difficult to reduce by gathering more information. Examples include long-range weather uncertainties, biological variations such as the natural growth rate of a fish population, and possibly levee performance. But other uncertainties can typically be mitigated by further information gathering. For example, new information naturally arrives regarding economic activities and even the valuation of the ecological impacts as more data become available.

With sunk costs, uncertainty and future learning, the traditional method of project evaluation based on the expected net present value is not efficient as it does not fully account for the value of future information in selecting and formulating the alternatives. In this paper, I discuss a new method of evaluation, called the real options approach, which can be used to deal with these kinds of projects. This method argues that, given the prospects of future information, projects that allow future flexibility to respond to the new information should be given more weight. The flexibility has a value, called option value, similar to the financial call or put options. Further, a given project may need to be postponed if the option value is high. The real options approach is being rapidly adopted in neoclassical investment analysis (Dixit & Pindyck, 1994) and in capital budgeting practices (Trigeorgis, 1996).

The real options approach has not been adopted in water project assessment, although it has attracted attention in general policy analysis (Metcalf & Rosenthal, 1995). The Principles and Guidelines, an assessment manual for federal water projects, explicitly describes how uncertainty should be incorporated in project evaluation. It requires the expected benefits and costs be calculated, and expected net present value (called NED-national economic development) be used to select the best alternative.

In this paper, I discuss how the real options approach can be applied to water project assessment. I start with a short description of the real option theory, followed by a discussion of the conditions under which this theory can be applied to water projects. I then present an example, the American River Watershed Project, to show how the new approach can help project selection and formulation.

REAL OPTION THEORY

One of the early motivations of real option theory was the uncertainty and irreversibility of natural resources development (Arrow & Fisher, 1974). When the development is irreversible, e.g., when the initial investment is sunk, or when the damage to the natural environment cannot be repaired, uncertainty implies that it is possible the development proves to be suboptimal in hindsight. Anticipating this possibility, the decisionmaker may have incentive to delay the development until more information becomes available, or to devise measures that maintain certain degrees of flexibility, such as by reducing the project size. In either way, the probability of "regretting" the irreversible investment is reduced. A project should be valued together with the associated future options, and the decision is made not only in terms of the scale of the project, but also its timing.

To see the role of information and timing, consider the following stylized example of an investment project that costs \$84 million and will last forever. Suppose the payoff of this project in the current period is known and equals p=\$10 million. Uncertainty in future payoffs arises due to a special regulation being debated. The nature of the regulation will become clear the next year, and the project's future annual payoff will be either 0.5p=\$5 million or 1.5p=\$15 million, depending on the outcome of the regulation. Based on the current information, the regulation can either be favorable or unfavorable with equal probability. The discount rate is ten percent.

The expected present value of the project is (10/0.1)-84=\$16 million, so the expected net present value

(NPV) approach would suggest investing now. But consider the alternative of holding the project and waiting one more year until the nature of the regulation is known. If in year two, the regulation tums out to be unfavorable, no investment is undertaken (since the payoff of $5 each year cannot overcome the investment cost of $84). If the regulation turns out to be favorable, the project is executed and the payoff is 15/0.1-84=$66 million. Given the probabilities of the two scenarios, the expected present value of the payoff of waiting in period one is (0.5)(66)/1.1=$30 million, which is higher than the payoff of investing now ($16 million). Thus, waiting generates a higher expected payoff than executing the project in period one. Note that the value of not investing now, given the option of investing later, is $30 million, rather than zero.

This example illustrates that the expected NPV criterion can lead to an inefficient decision in project assessment. An essential feature of the real options approach is that projects should be valued in a *dynamic* framework. In our example, where only one investment alternative is provided, this alternative has to compete with *itself* at a later date (and with more information). Through delaying the project, a more informed decision can be made that avoids some (or all, as in this example) downside risks. The cost of delaying arises from discounting: the earlier the investment, the earlier the net benefits start to accrue.

A water project may involve many components, some of which can be delayed and others cannot. Some components may in fact be partially reversible, subject to certain adjustment costs. Different combinations of the components form competing project alternatives, each with its own degree of irreversibility and cost of delay. Projects with multiple components have been studied in the real options literature. Both Dixit and Pindyck (1994) and Trigeorgis (1996) review studies of multiple options, where investments on a project's components are executed in a certain order. Facing uncertainty, a decisionmaker may choose to invest in some components, holding off others until more information becomes available. For example, an oil company may choose to undertake exploration in a field, but postpone extraction until more favorable market conditions materialize.

REAL OPTIONS IN WATER PROJECTS

As indicated in the previous section, the real options approach is more efficient than the expected NPV criterion if a water project satisfies all of the following conditions: (1) the outcome of the project is uncertain; (2) future information can be gathered that helps better evaluate the project; (3) the project or some of its components can be delayed; and (4) there are adjustment costs in reversing the project or its components. Some of these conditions epitomize the main features of water projects. As Reisner (1986) argues, the root of the current environmental challenges facing many water projects in the Western U.S. lies in the difficulty of reversing earlier developments (condition (4)) which are deemed excessive based on new information such as people's tastes for the environment (conditions (1) and (2)). Next we discuss how these conditions arise in and their implications for water project formulation.

Uncertainty and Future Information

We discussed earlier that a water project faces an array of uncertainties in both the natural and social-economic factors that affect its net payoff. Future information may arrive for some of these factors. Compared with the uncertainty and risk analysis procedure currently required in the Principles and Guidelines, real option theory demands description not only of the uncertain factors, but also the likelihood and nature of future information about these factors.

Characterizing possible future information is *not* conducting a point forecast of the values of the random variables of interest. Rather, it requires specifying the possible future signals that can shed light on the variables' values, and how these signals relate to the variables. For example, if the random variable is growth in urban demand for drinking water, the signals may be population growth or a new water rate structure in the future. The decisionmaker may describe several scenarios in which these signals evolve (i.e., the possible values of the signals), the time when the signals can be observed, and the likely demand for water under each scenario.

If the water project takes a lengthy time to complete, or if the components of the project are executed sequentially, performance of the finished components may generate information that can help the design (or redesign) of later components. For example, suppose an irrigation project involves expanding the storage capacity of an existing dam in the first stage, and possibly a new dam in the second stage depending on the future demand. Suppose further that by observing how water consumption responds to the increased water supply after completion of the first stage, the policy maker can obtain more information about the future demand. Then the new information after the first stage may help determine the necessity and the scale of the second component. In fact, in this case, the design of the first stage should even be modified to generate more information about the future demand, if the information is important. *Ceteris paribus*, components with higher information contents, i.e., those that generate more information about the uncertainties, should be executed earlier.

Possibility of Delay

Whether or not a water project or some of its components can be postponed for more information depends on the specific circumstances surrounding the project. Delay can be extremely costly in some cases. For example, facing imminent flooding risk, postponing preventive measures such as strengthening levees may lead to devastating results. The cost of delay can be relatively low in other cases, arising mainly from discounting. For instance, without strong demand for irrigation water, building a major irrigation and hydroelectric dam can be delayed for more information. Different components of a major project may also have different costs of delay. If works on levees and other existing flood control facilities provide sufficient protection against flooding in the short run, major components such as building a new flood control dam can be delayed. Finally, the components may have to occur in a certain order, i.e., delaying a certain component may postpone other subsequent components, raising the cost of delay.

A water project typically includes numerous components, and the formulation process of alternative project plans involves specifying these components and forming different combinations of them. According to the real options approach, the cost of delay and the information contents should be considered in *formulating* the individual components and in forming and choosing the combinations. *Ceteris paribus*, components with lower costs of delay and higher information contents are preferred, because of their higher net values, which include both the expected payoffs and the associated option values. If possible, components with higher information content and higher costs of delay should be executed earlier.

Sometimes there exist methods that can reduce the costs of delay for some projects. Non-structural measures such as flood zone management or water markets can reduce the cost of delaying a flood control dam or an irrigation dam. In project design, policymakers should also consider such measures that mainly serve to reduce the delay costs of other components.

Adjustment Costs in Reversing Earlier Development

Large-scale water projects such as major dams are difficult or impossible to be completely reversed. The proposal to remove two (relatively small) dams on the Elwha River (in the Olympic National Park in the state of Washington) was debated for decades before the Record of Decision was signed in 1996. The acquisition of the dams by the Department of Interior was completed only in 2000. However, individual components of a large water project may be reversible at relatively low costs, and even when a project is not reversible, there are measures that can partially reverse the *impacts* of the water project. The restoration efforts by the Bureau of Reclamation and the Army Corps are aimed precisely at (partially) mitigating the damages of the existing water projects, particularly large dams, on biological resources.

Allowing costly restoration is likely to raise the expected payoff of a water project, since restoration adds an option of mitigating the damages or increasing the benefits if *ex post* the project causes serious damages. It also favors more projects or components that are less costly to reverse. For example, if a water regulation leads to too much environmental damage, it may be reversed relatively easily. But if an irrigation dam severely reduces the fish population, restoration can be very costly. Then other things equal, the nonstructural measure (i.e., the regulation) should be favored relative to the structural measure (i.e., the dam). Of course, some of the non-structural measures require significant policy changes that are difficult to make or reverse, leading to policy related option values themselves (Pindyck, 1999; Zhao & Kling, 2000).

AN EXAMPLE

To illustrate how the real options approach can be applied to water projects, we analyze a study conducted by the Army Corps in 1995 to provide flood protection for the Sacramento area in California, the American River Watershed Project. The study was conducted to supplement the Corps' 1991 American River Watershed Investigation Feasibility Report, which recommended construction of levee in Natomas area and a flood detention dam near Auburn area.

BACKGROUND

The reassessment of flood risk in the Sacramento area following the February 1986 "storm of record" indicated that the existing protection is substantially below 100-year level. Further study indicated that the Sacramento area needs at least 200-year protection. The Corps considered 17 individual flood protection measures, selected 6 of them (through incremental analysis) to form an initial array of 9 alternatives, and finally considered 3 candidate plans in detail. The Folsom Modification Plan involves some work on Folsom Reservoir (such as increasing its flood storage and lowering the main spillway) and some levee work along lower American River. It provides 180-year protection. The Folsom Stepped Release Plan requires more work on Folsom Reservoir (such as modifying surcharge storage space and increasing the objective release) and downstream American River, and achieves 235-year protection. The Detention Dam Plan includes a 508-foot-high flood detention dam with a detention capacity of 894,000 acre-feet near Auburn (a dry dam with the option of converting into permanent irrigation or hydroelectric dam in the future), and some work along lower American River. It provides 500-year protection. Table 1 presents the components of the three plans.

For each plan, the Corps evaluated its expected reduction in flood risk, and based on the flood zone structures/values, the expected reduction in flood damage (which is also the expected benefit of flood prevention). It then compared the benefits with the costs to calculate the net economic values. These figures are presented in Table 2, where a discount rate of 7.75 percent is used to calculate the NPVs. The National Economic Development (NED) plan is thus the Detention Dam Plan.

Uncertainties

Water runs through the upper American River into Folsom Reservoir, which subsequently releases the water (subject to operation procedures) into downstream American River. The discharge causes water in lower American River to reach certain stages (different points along the river may have different stages). Depending on the levee system and other features of the river, there is a probability of levee failure and flooding for each stage of river water. The actual damage of flooding depends on the magnitude of the flood and features of the flood plain development. The process of rainfall causing flood damages is illustrated in Figure 1.

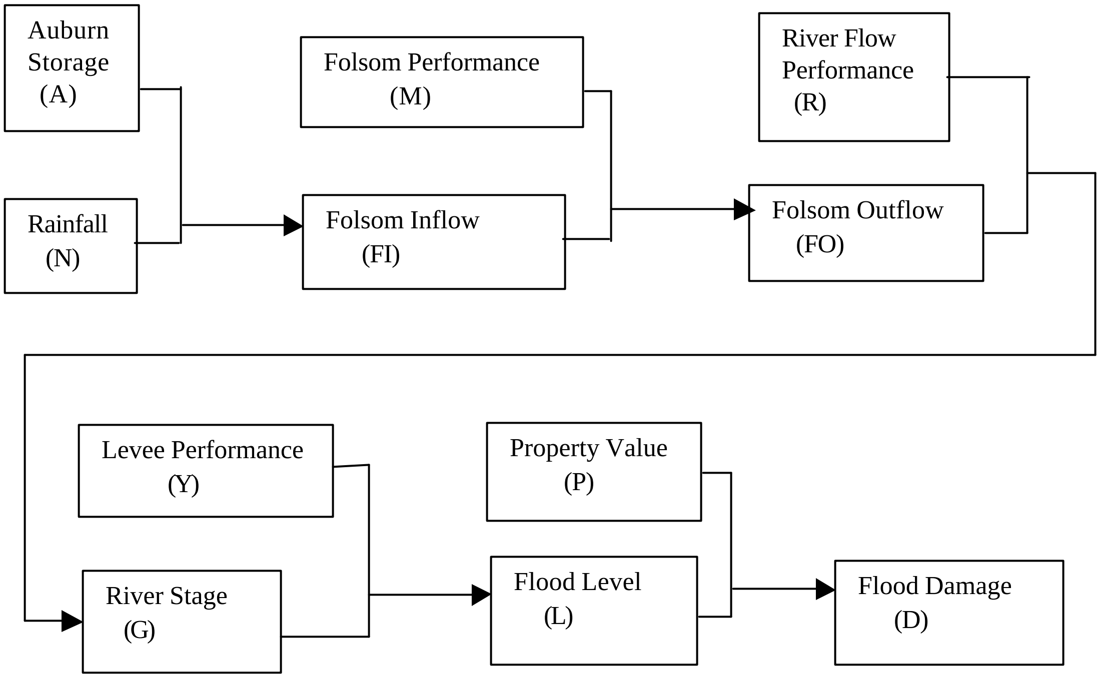

Figure 1. The Process of Flood Damage

Therefore, flood damage can be summarized by a function, mapping the state variables of the system into flood damage: $D = f(S)$, where $S = (N, A, M, R, Y, P)$ is a vector of the state variables, including rainfall level (N), the storage capacity of Auburn Dam (A), the state of Folsom Reservoir operation (M), the capacity of American River (R), the state of the levee system along American River (Y), and the structure value in the flood zone (P). These variables also describe the uncertainties of the Project, because the values of these variables are typically stochastic. The uncertainties are described by the distributions of the state variables.

The purpose of the Project is to adopt measures to change the values, or more precisely the distributions, of the state variables so as to reduce the expected flood damage. For example, building Auburn Dam raises A and reduces floodwater inflow to Folsom. Increasing flood storage in Folsom enhances the performance of Folsom M, and reduces the outflow for a given inflow of floodwater. Raising levees along downstream American River improves levee performance Y, and reduces the probability of flooding for a certain river stage. Proper flood plain management curtails the structure value subject to flooding P, and reduces the magnitude of damage for a certain flood level. Comparing the distributions of the state variables before and after a certain plan, the Corps calculated the expected reduction of flood damage, or the flood prevention benefits of this plan.

The Corps considered the uncertainties of rainfall N, Folsom Reservoir performance M, and lower American River flow performance R, but ignored uncertainties of levee performance Y and flood plain development represented by structure value P. It argued that the magnitude of the economic uncertainty is low because the social economic structure in the flood plain was known. However, since the project is to provide flood prevention for over 100 years, the future social economic uncertainties will be of a very high magnitude. In addition, although the hydraulic and hydrologic characters may not change a lot during the 100 years of project life, the social economic characters will involve significant changes in this period.

The real options approach requires that, in addition to describing the uncertainties of *S*, the Corps should also estimate the future evolution of information about *S*. Such information is most likely to occur for economic uncertainty, since economic activities are more likely to experience significant changes in the future. The economic volatility has been highlighted by the economic boom in the region in recent years, and the imminent slow down that is expanding from Silicon Valley. In examining the Corps' study, I therefore focus on the economic uncertainty and its impacts on the Project's evaluation.

Project Components

Of the three plans the Corps considered, there is substantial overlap of the components between the Folsom Modification Plan and the Stepped Release Plan, as shown in Table 1. The Stepped Release plan essentially expands the Modification plan by adding more independent components downstream from the Folsom Reservoir, thereby increasing the flood control capability. The Detention Dam Plan replaces most of the components of the other two by the proposed Auburn Dam.

As we discussed in the last section, a key feature of the real options approach is allowing responses to future new information. We cannot completely specify the possible future responses without a detailed engineering analysis. However, for illustration purposes, we can consider a plan that starts with Folsom Modification, with the *option* of expanding it to Stepped Release if the new information deems the expansion necessary. We call this alternative the Optional Release Plan.

The Optional Release Plan

Suppose after some time, say ten years, there will be new information about the economic development and thus the benefits of flood control in the Sacramento area. With the new information, estimates about the annual benefits of the three plans will be modified. Suppose the nature of the uncertainties and the new information is such that the annual benefits can be 50 percent lower or 50 percent higher than the current estimate, with equal probability.[1] Folsom Modification will be expanded to Stepped Release only if the new information indicates the expansion to be optimal. The cost of the expansion is the cost of the additional components in the Stepped Release, which is 528-327=201 million dollars (see Table 2).

The costs and benefits of the expansion option are presented in Table 3. If in ten years, new information indicates that the flood benefit is high, i.e., 50 percent higher than the current estimate, the additional benefit of the expansion, at $22.5 million per year, more than compensates the required cost of the expansion. In this case, Folsom Modification should be expanded to Stepped Release, and the net benefit, discounted to period zero, is about $42 million. If, however, new information indicates that the annual benefit of flood control is lower than expected, the additional benefit of expansion cannot justify the costs, and Folsom Modification will not be expanded. In this case, nothing will be done in year ten, and there are no additional costs or benefits. Since there is a 50 percent probability that the expansion will occur, the expected benefit of the expansion option is 0.5*42=21 million dollars. Thus the net benefit of the Optional Release is the sum of the benefits of Folsom Modification and the expansion option, or 576 + 21 = 597 million dollars.

The benefits of the option and the Optional Release increase in the amount of future information (or the level of current uncertainty), and in the speed at which the information arrives. More information increases the value of the option that uses the new information. The speed of the new information matters because of discounting. For example, if in year ten the annual benefits of flood control will be 80 percent higher or lower than expected, the value of the option becomes $35 million. On the other hand, if the same amount of information (i.e., 50 percent) arrives in year five, instead of year ten, the value of the option is about $31 million.

Similar methods can be used to analyze more complicated situations such as gradual (or continuous) arrival of new information, partial but costly reversal of finished components, additional adjustment costs for constructing new components, and active gathering of new information. Our simple example only roughly illustrates how the real options approach can be implemented and the additional benefits of this approach.

FINAL REMARKS

From our discussion, it is clear that using the real options approach leads to additional benefits to water projects by the possibility of responding to new information. It can also be expanded to incorporate environmental damages that are typically not included in the NED account due to the difficulty in attaching monetary values to the damages. Failure to include these damages has been subject to much criticism. If a range of the damage values can be specified, and future detailed studies can better estimate the values, the real options approach can incorporate these values.

This approach is also applicable to restoration projects that require significant sunk costs. The only difference is that delaying a restoration project may lead to irreversible damages. Here there are two option values working in the opposite direction: the option to delay the project for better information, and the option to avoid the damages of the water project by executing the project early. The two values have to be balanced together with the expected payoffs of the projects to select the best alternative. Kolstad (1996) presents a conceptual framework for analyzing such tradeoffs.

The real options approach also incurs additional costs of more careful formulation of the project components, future information, and necessary future adjustments. The additional flexibility may also invite more opportunities for "manipulation" of the data. A standardized procedure of carrying out such analysis is needed for the approach to reach its full potential.

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Table 1. Plan Components

Components	**Folsom Modification**	Stepped Release	**Detention Dam**
Folsom Dam and Reservoir			
• Lower spillway crest and replace main gates	•	•	
• Extend stilling basin	•	•	
• Enlarge eight existing river outlets	•	•	
• Modify surcharge storage operation	•	•	
• Replace three emergency gates	•	•	
• Increase flood control storage space	•		
• Maintain flood control storage space		•	
• Telemeter upstream gage /emergency warming system	•	•	
• Increase objective release		•	•
Lower American River			
• Slurry wall	•	•	•
• Raise Levees		•	
• Other modifications		•	
Downstream from American River			
• Modify Sacramento weir and bypass		•	
• Modify Yolo bypass levees		•	
Natomas			
Additional levee construction	•	•	
Upstream			
• Auburn Dam			•

Table 2. Plan Costs and Benefits (million dollars)

Plans	Folsom Modification	Stepped Release	Auburn Dam
Fixed Cost	327	528	934
Annual benefit	70	85	134
NPV	576	568	794

Table 3. Costs and Benefits of Expansion (million dollars)

	Higher Benefit	Lower Benefit
Annual Benefits		
Folsom Modification	105	35
Stepped Release	127.5	42.5
Fixed Cost of Expansion	201	201
Annual Benefit of Expansion	22.5	7.5
Net Benefit of Expansion	88.97	<0
NPV (year zero) Benefit	42.18	<0

END NOTES

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[1] The annual benefits are calculated taking into consideration of future economic growth. New information thus can be about the level of the achieved growth after ten years, or the future growth rate. For example, if there is substantial inflow of investment from Silicon Valley, the estimates will have to be modified.