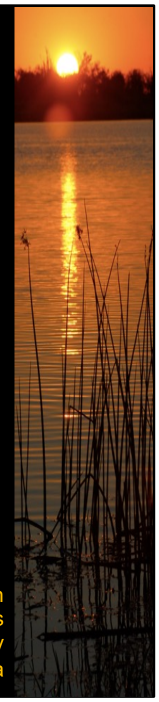
2026 International Summer Course on Environmental and Ecological System Engineering

Part A: Environmental Accounting and Systems Thinking (EAST)

# Lecture 8:

# Emergy Evaluation of Alternatives



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In this lecture we move from the International scale down several hierarchical levels to applying emergy to evaluation of environmental alternatives.

## Organization…

The Challenge of Environmental Decisions

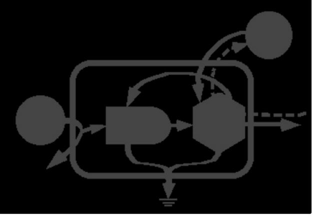
A Common Biophysical Basis for Comparison

Case Study 1 — Crystal River Power Plant

Case Study 2 — Rodman Dam Restoration

Case Study 3 — Phosphate Mine Restoration

Principles of Emergy Decision Support




Understanding a system is only part of the challenge.
Environmental scientists, engineers, and policy makers must eventually make decisions.

Should we build a dam or remove it?

Should we restore a wetland or develop it?

Should we solve an environmental problem with technology, or should we rely on the natural functions of ecosystems?

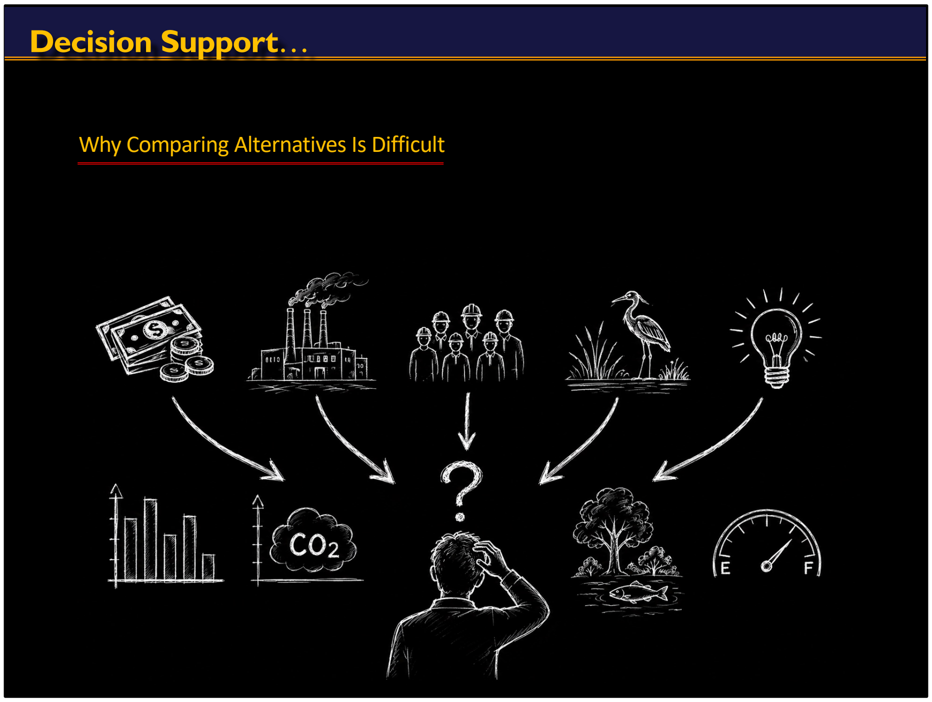
These decisions are rarely simple. Every alternative has costs, benefits, and unintended consequences.

The question is not simply, **"Which alternative costs less?"**

The deeper question is,

**"Which alternative provides the greatest overall benefit while requiring the least environmental support?"**

In this lecture we will see how emergy provides a common framework for comparing alternatives that would otherwise be very difficult to evaluate.




Environmental management almost always involves choosing among alternatives.

At first glance, that may seem straightforward. We simply compare the alternatives and select the best one.

But what does **"best"** actually mean?

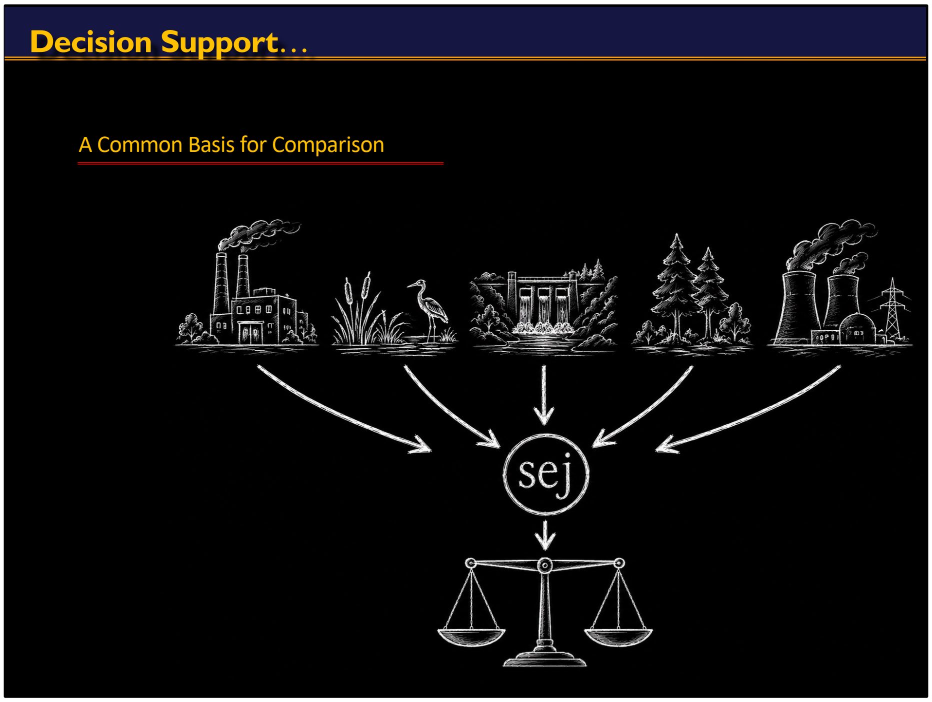
One alternative may cost less money. Another may create more jobs. A third may protect wildlife, reduce pollution, or preserve ecosystem services. Each provides different benefits, and each has different costs.

The problem is that these quantities are measured in completely different ways. Money is measured in dollars. Energy is measured in joules. Carbon emissions are measured in tonnes. Biodiversity cannot be measured with a single number at all.

How do we compare things that are measured in different units?

This is one of the fundamental challenges of environmental decision making. Without a common basis for comparison, every group naturally focuses on the quantity it considers most important.

So obviously emergy accounting can play that role.




Most frequently environmental alternatives are evaluated in monetary units.

However….

Generally, alternatives when compared using monetary methods result in interesting assumptions

Make up a Market.

Ask people what it is worth

Estimate based on what people will pay for something else.

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A wetland provides habitat, nutrient cycling, and flood protection.
A factory produces products, jobs, and economic income.
A dam generates electricity but also changes river ecosystems.
Each contributes something different.
Emergy does not eliminate these differences.
Instead, it evaluates all of the available energy that was previously required, directly and indirectly, to create and maintain each alternative.
By expressing that support in a common unit, solar emjoules, we can compare systems that would otherwise have no common basis for evaluation.
Notice that emergy is not replacing economics, ecology, or engineering.
Instead, it provides a common biophysical framework that allows all of these perspectives to be considered together.
This is why emergy is such a powerful tool for evaluating environmental alternatives.


What makes one alternative better than another?

The answer is not simply that one alternative has lower emergy than another.

If it were, the best solution would always be to do nothing.

Environmental decisions almost always involve trade-offs.

One alternative may require more resources to build but provide greater long-term benefits.

Another may minimize construction costs but reduce ecosystem productivity.

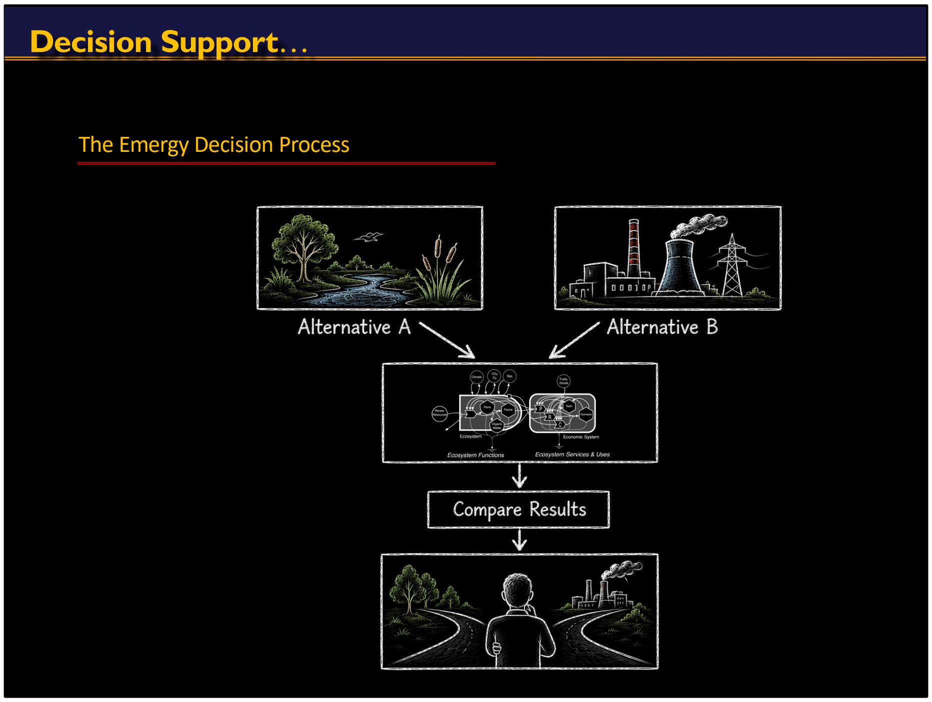
Still another may preserve natural systems while limiting economic opportunities.

Emergy does not eliminate these trade-offs.

Instead, it allows us to evaluate all alternatives using the same accounting framework so that the trade-offs become visible.

The goal is not to find a perfect solution.

The goal is to understand the consequences of each alternative more completely and make better-informed decisions.




The process begins by defining the alternatives.

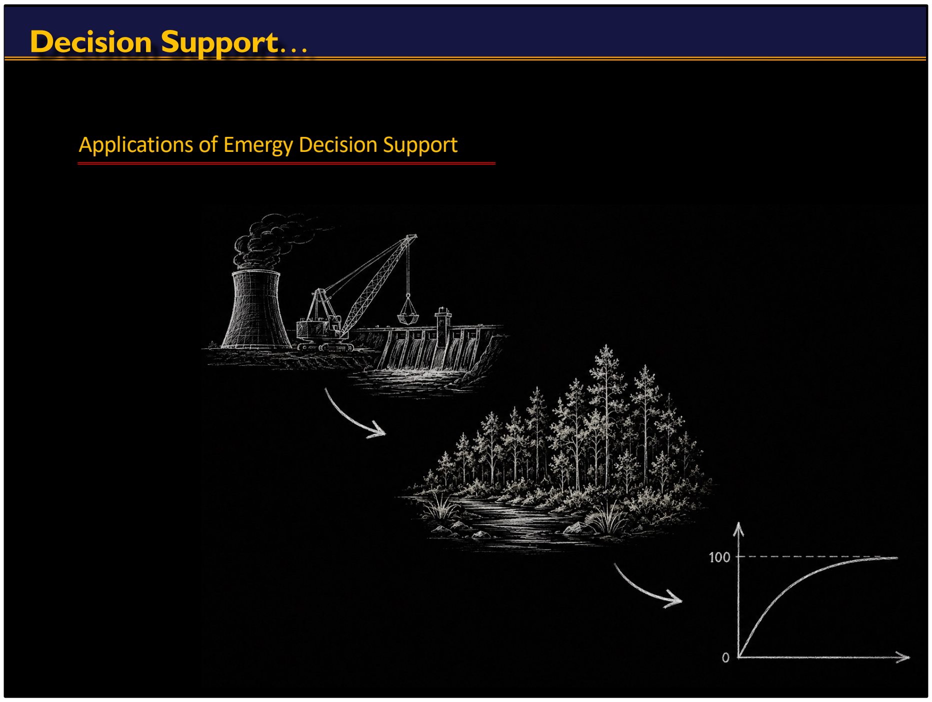
Each alternative is evaluated independently using the same emergy accounting procedures.

We identify the available energy required to produce each system, account for both renewable and nonrenewable inputs, and evaluate the goods, services, and environmental changes associated with each alternative.

Because every alternative has been analyzed using the same accounting framework, meaningful comparisons become possible.

The purpose of the analysis is not to tell us what decision must be made.

Instead, it provides objective biophysical information that helps decision makers understand the consequences of each alternative before making a choice.

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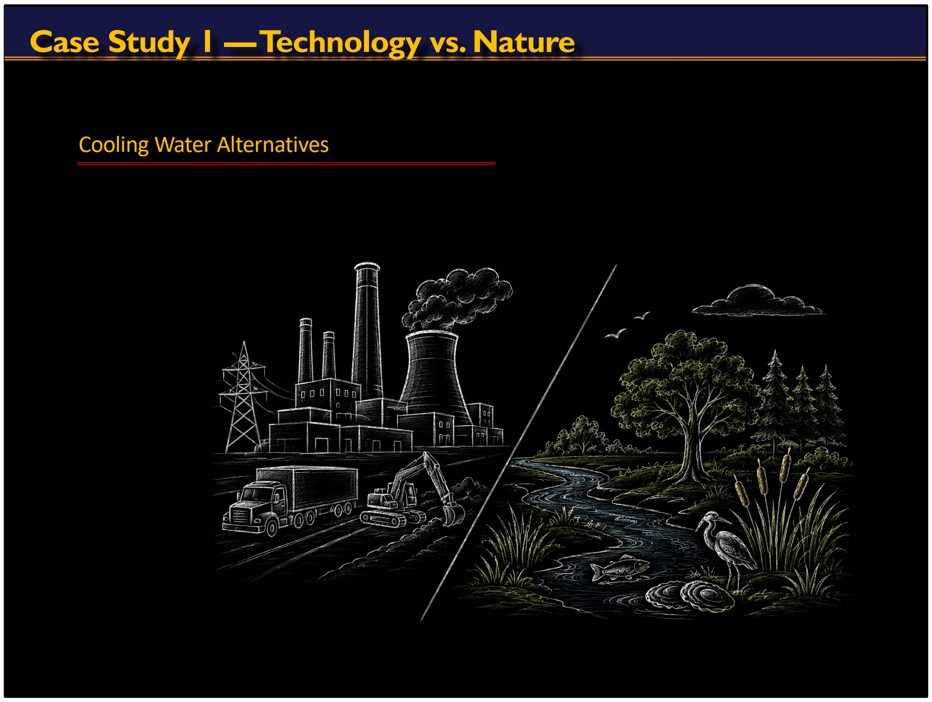
In the remainder of this lecture, we will examine three very different applications of emergy decision support.

The first asks whether a natural ecosystem function should be replaced with engineered technology.

The second asks whether an existing technological system should be maintained or whether a natural ecosystem should be restored.

The third asks a different question altogether. It explores how we evaluate restoration projects whose costs occur today, but whose ecological benefits may not be realized for many decades.

As we move through each case study, notice that the question changes, but the method remains the same.

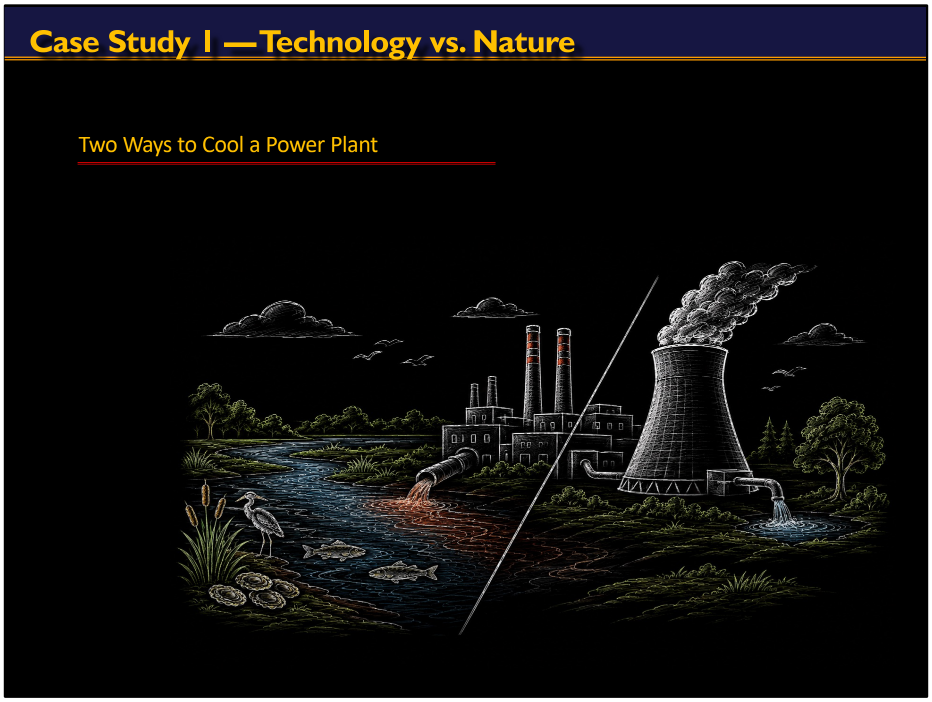



Many environmental problems present a similar question.

Should we rely on the natural functions of ecosystems, or should we replace those functions with technology?

Sometimes technology clearly provides the better solution. In other situations, natural systems may accomplish the same objective with far fewer resources.

Our first case study examines this question in the context of cooling a large electric power plant.




Every thermal power plant must remove large amounts of waste heat from the generating system.

There are two basic ways to accomplish this.

The first is to withdraw water from a nearby river, lake, or estuary, circulate it through the plant, and then return it at a higher temperature.

The second is to construct a cooling tower that removes most of the heat before the water is discharged.

Both alternatives accomplish the same engineering objective.

But they do so in very different ways.

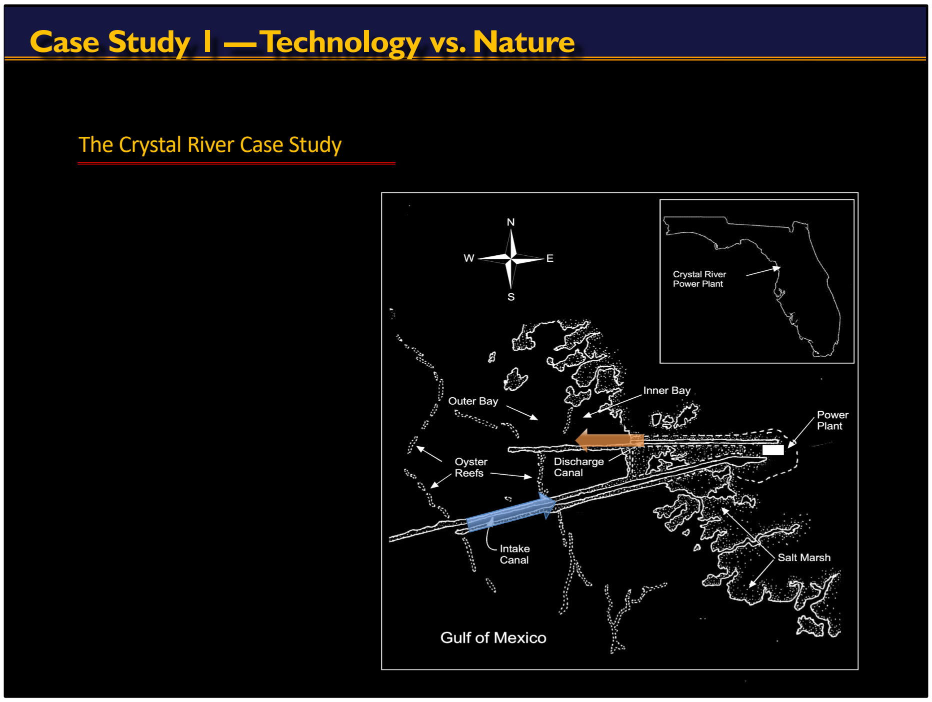
One relies primarily on the assimilative capacity of the surrounding ecosystem.

The other relies on additional technology, materials, energy, and human services.

The question is not simply which system works.

Both do.

The question is which alternative requires fewer total resources when all ecological and technological contributions are considered together.




This study was conducted at the Crystal River Power Plant on the west coast of Florida.

The plant used seawater drawn from the Gulf of Mexico to cool its generating units.

After passing through the condensers, the warmed water was discharged into a nearby estuary.

The estuary was not simply a body of water receiving waste heat.

It was a productive ecosystem containing tidal marshes, oyster reefs, fish, plankton, and many other organisms.

As additional generating units were planned, an important question emerged.

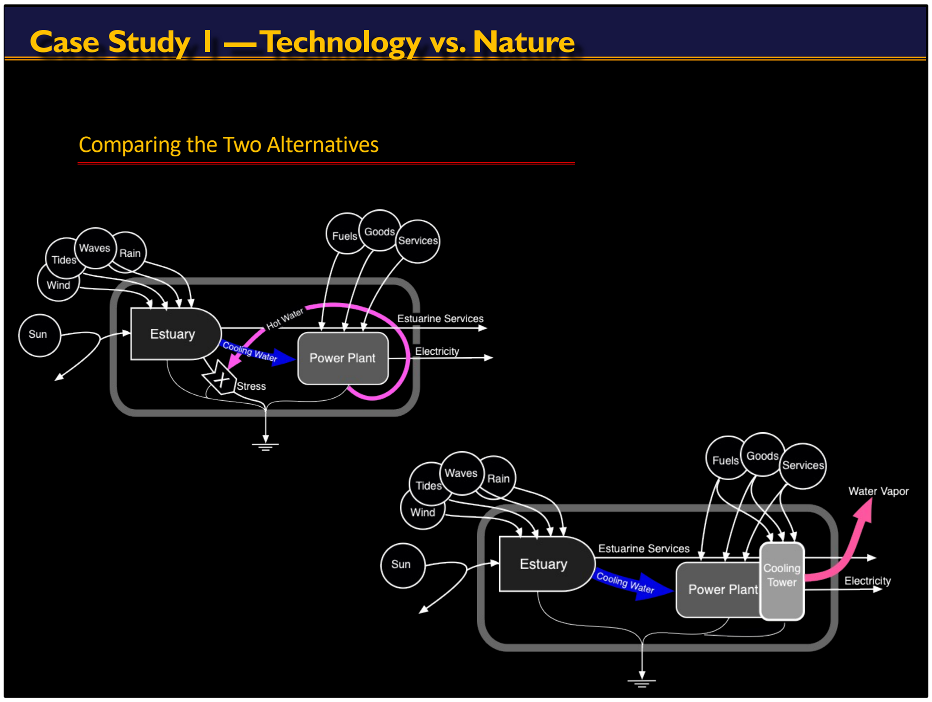
Should the plant continue to use the estuary for cooling, or should it construct an expensive cooling tower to remove the heat before the water was discharged?

Notice that this is not simply an engineering problem.

It is a systems problem.

The estuary performs useful ecological functions, while the cooling tower performs the same physical function using additional materials, energy, and human services.

Emergy analysis allows us to compare these two alternatives within the same accounting framework.




This diagram shows the emergy evaluation of those two alternatives.

Notice that the two systems are almost identical. Both produce electricity. Both receive fuels, goods, and services. Both depend on the same surrounding environment.

The important difference is how the waste heat is managed.

In the upper alternative, the estuary absorbs the additional heat from the discharge water. As water temperatures increase, thermal stress reduces some of the ecological functions and ecosystem services that the estuary normally provides.

In the lower alternative, a cooling tower removes most of that heat before the water reaches the estuary. This reduces thermal stress and preserves ecological functions.

However, the cooling tower is itself a complex technological system that must be constructed, operated, and maintained. It requires concrete, steel, machinery, fuel, labor, and other resources, all of which represent additional emergy investments.

The decision therefore involves a trade-off.

Building the cooling tower increases the emergy invested in technology.

Not building the cooling tower increases the loss of ecological functions within the estuary.

## Case Study I — Technology vs. Nature

### Results of the Emergy Evaluation

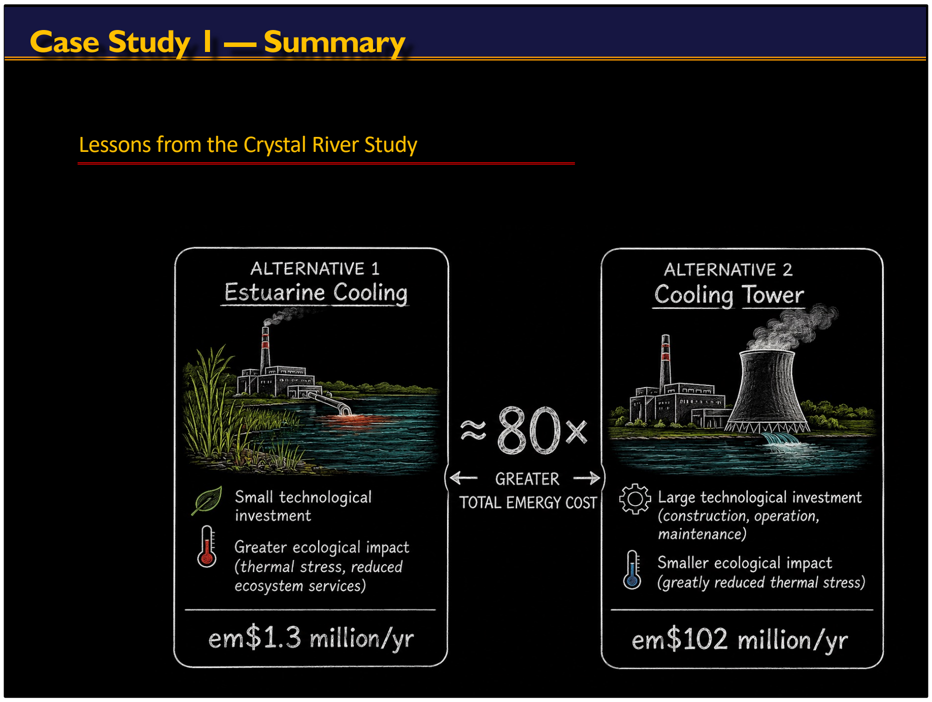
**Emergy Evaluation of Cooling Towers**

| Item | Emergy ($x10^{15}$ sej/yr) | Emdollars ($x10^{3}$ em$/yr) |
|---|---|---|
| Ecosystem Losses | | |
| Ecosystems displaced | -469.7 | -140.6 |
| Construction costs | | |
| Materials | -5197.2 | -1556.1 |
| Energy | -56622.9 | -16953 |
| Labor & Services | -278356.6 | -83340.3 |
| Total cooling tower costs | -340646.4 | -101990 |

**Emergy Evaluation of Estuarine Cooling**

| Item | Emergy ($x10^{15}$ sej/yr) | Emdollars ($x10^{3}$ em$/yr) |
|---|---|---|
| Ecosystem Losses | | |
| Cooling canal losses | -328.9 | -98.5 |
| Ecosystem losses from constructi | -694.8 | -208 |
| Thermally induced ecosystem los | -4353.5 | -1303.5 |
| Total Ecological costs | -5377.2 | -1609.9 |
| Ecosystem Gaines | | |
| Productivity gaines | 1162.6 | 348.1 |
| Net ecosystem Impact | -4214.6 | -1261.8 |

The tables summarize the annual costs associated with each alternative.
The second column reports the results in solar emjoules, while the third column converts those values to **emdollars** using the U.S. National Emprice.
Although the accounting is performed in emergy units, expressing the results as emdollars provides a scale that is much more intuitive for most people.
For **estuarine cooling**, the principal cost is the reduction in ecosystem functions caused by thermal stress.
After accounting for both ecological losses and productivity gains, the net impact is approximately **em$1.3 million per year**.
For the **cooling tower**, the ecological impacts within the estuary are greatly reduced, but constructing and operating the tower requires substantial investments in materials, energy, labor, and services.
The total cost is approximately **em$102 million per year**.
The comparison is striking. The additional resources required to build and operate the cooling tower are roughly **eighty times greater** than the ecological losses associated with thermal stress in the estuary.
This does **not** imply that cooling towers are undesirable, nor does it suggest that ecological losses should be ignored. Rather, it demonstrates the value of emergy accounting.
By expressing both technological investments and ecological impacts in the same units, emergy allows us to compare alternatives that would otherwise be impossible to evaluate objectively.
This is the essence of systems thinking. Good environmental decisions require more than solving an engineering problem or meeting a regulatory standard. They require understanding the full biophysical consequences of each alternative before deciding which path provides the greatest overall benefit.




This comparison illustrates one of the central ideas of emergy evaluation.

The cooling tower successfully reduces thermal stress on the estuary, but it does so by replacing a natural ecosystem function with an engineered one.

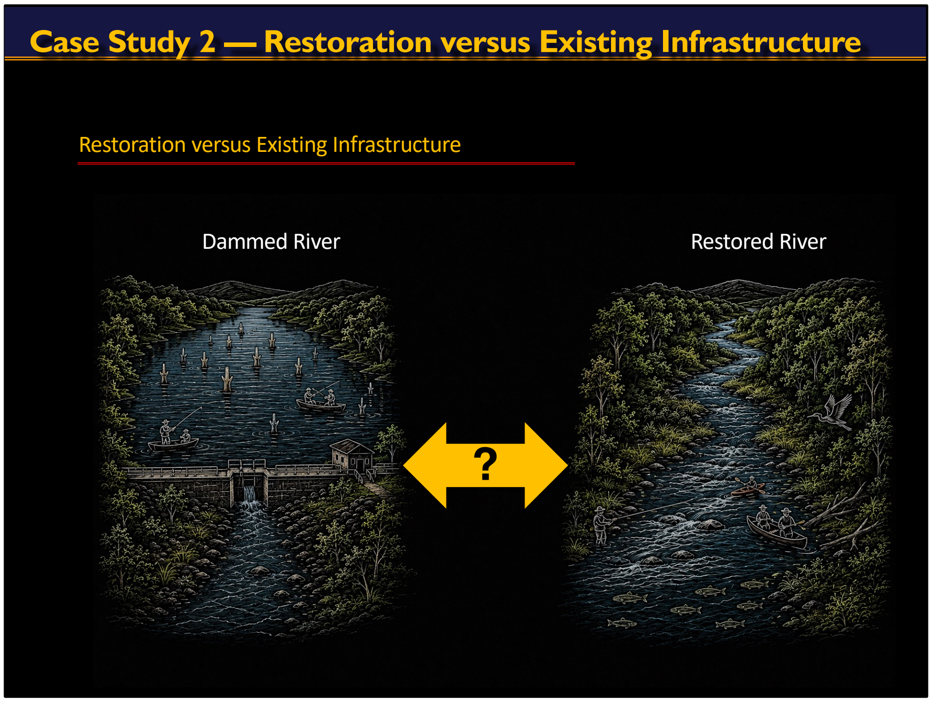
Constructing and operating that technology requires substantial investments in materials, energy, labor, and infrastructure.

In this particular case, those technological investments were approximately eighty times greater than the ecological losses associated with thermal stress in the estuary.

This does not imply that cooling towers should never be built. Every site is different, and every evaluation depends on the characteristics of the system being studied.

Instead, the lesson is that technology is not free. When we replace natural processes with engineered systems, we should evaluate not only the environmental benefits but also the additional resources required to provide the same function.

Emergy provides a quantitative framework for making that comparison.




What are the costs and benefits of dam removal?

Across the world, thousands of dams were constructed during the last century to provide water storage, flood control, navigation, and recreation. Many have served society for decades, but as these structures age, a new question is being asked.

Should we continue maintaining existing infrastructure, or should we restore the river to its natural condition?

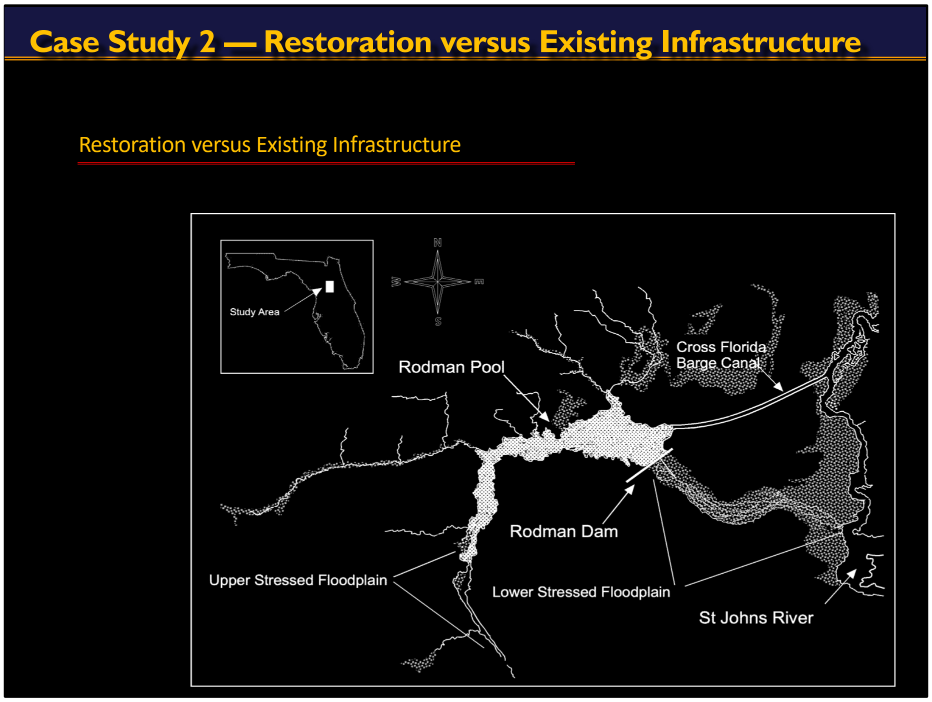
Neither alternative is free.

Keeping the dam preserves the services provided by the reservoir, but it also maintains the environmental changes created by the dam.

Removing the dam restores many natural river functions, but it also requires giving up some of the benefits that people have come to depend upon.

Once again, the question is not simply which alternative is more desirable.

The question is which alternative provides the greatest overall benefit when **both** the human and ecological consequences are considered together..

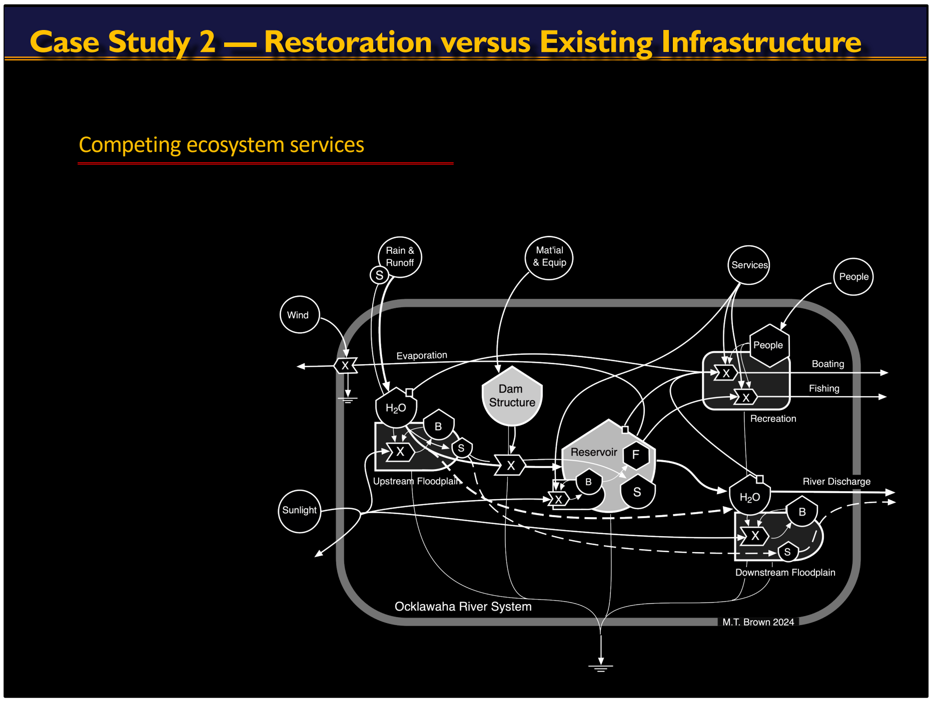



The Rodman Dam was constructed in the 1960s as part of the Cross Florida Barge Canal, a project intended to connect the Gulf of Mexico with the Atlantic Ocean. Although the canal was never completed, the dam remained, creating a large reservoir where a free-flowing river once existed.

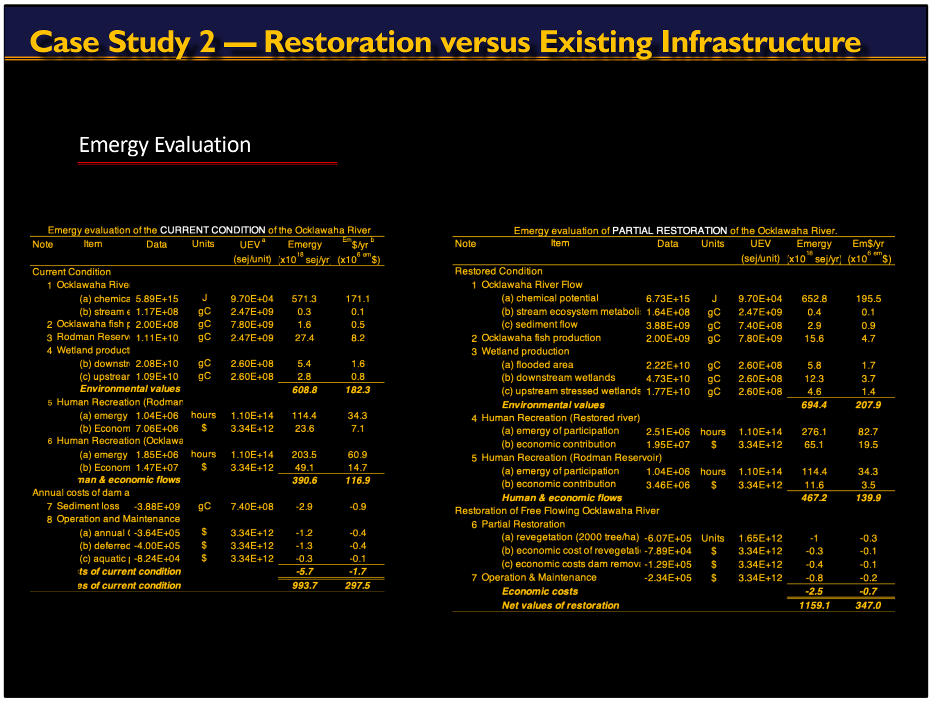
Today, the reservoir provides recreational opportunities, particularly boating and nationally recognized bass fishing. At the same time, the dam blocks fish migration, alters the river's natural flow, and has transformed much of the original floodplain forest into a permanently flooded reservoir.

More than fifty years after its construction, the question is no longer why the dam was built. The question is whether the benefits of maintaining the reservoir continue to outweigh the ecological benefits of restoring the river.

This is exactly the type of question that emergy evaluation is designed to address. Rather than focusing on a single objective, such as recreation or ecosystem restoration, emergy allows us to compare the complete set of human and ecological contributions associated with each alternative.




This systems diagram shows why the Rodman Dam controversy is not a simple choice between people and nature.
The dam created a reservoir, and that reservoir now supports boating, fishing, and other forms of recreation.
Those are real benefits, and they matter to the people who use the reservoir.
But the dam also changed the river system.
It flooded part of the floodplain forest, reduced the free flow of water and sediment downstream, and blocked ecological pathways that once connected the lower river, the upper river, and Silver Springs.
So the alternatives involve competing ecosystem services.
Maintaining the dam preserves the reservoir services that people currently value.
Restoring the river would recover floodplain forest, improve river flow, reconnect ecological pathways, and increase long-term ecosystem function.
The role of emergy evaluation is to account for both sides of this system—not only the human use of the reservoir, and not only the ecological benefits of restoration, but the full set of flows, storages, and services created by each alternative.




Emergy evaluation of the CURRENT CONDITION of the Ocklawaha River

| Note | Item | Data | Units | UEV[a] (sej/unit) | Emergy ($x10^{18}$ sej/yr) | Em$/yr[b] ($x10^{6}$ em$) |
|---|---|---|---|---|---|---|
| Current Condition | | | | | | |
| 1 | Ocklawaha Rive | | | | | |
| | (a) chemica | 5.89E+15 | J | 9.70E+04 | 571.3 | 171.1 |
| | (b) stream e | 1.17E+08 | gC | 2.47E+09 | 0.3 | 0.1 |
| 2 | Ocklawaha fish p | 2.00E+08 | gC | 7.80E+09 | 1.6 | 0.5 |
| 3 | Rodman Reserv | 1.11E+10 | gC | 2.47E+09 | 27.4 | 8.2 |
| 4 | Wetland producti | | | | | |
| | (b) downstr | 2.08E+10 | gC | 2.60E+08 | 5.4 | 1.6 |
| | (c) upstrear | 1.09E+10 | gC | 2.60E+08 | 2.8 | 0.8 |
| | ***Environmental values*** | | | | ***608.8*** | ***182.3*** |
| 5 | Human Recreation (Rodman | | | | | |
| | (a) emergy | 1.04E+06 | hours | 1.10E+14 | 114.4 | 34.3 |
| | (b) Econom | 7.06E+06 | $ | 3.34E+12 | 23.6 | 7.1 |
| 6 | Human Recreation (Ocklawa | | | | | |
| | (a) emergy | 1.85E+06 | hours | 1.10E+14 | 203.5 | 60.9 |
| | (b) Econom | 1.47E+07 | $ | 3.34E+12 | 49.1 | 14.7 |
| | ***man & economic flows*** | | | | ***390.6*** | ***116.9*** |
| Annual costs of dam a | | | | | | |
| 7 | Sediment loss | -3.88E+09 | gC | 7.40E+08 | -2.9 | -0.9 |
| 8 | Operation and Maintenance | | | | | |
| | (a) annual ( | -3.64E+05 | $ | 3.34E+12 | -1.2 | -0.4 |
| | (b) deferred | -4.00E+05 | $ | 3.34E+12 | -1.3 | -0.4 |
| | (c) aquatic p | -8.24E+04 | $ | 3.34E+12 | -0.3 | -0.1 |
| | ***ts of current condition*** | | | | ***-5.7*** | ***-1.7*** |
| | ***es of current condition*** | | | | ***993.7*** | ***297.5*** |

Emergy evaluation of PARTIAL RESTORATION of the Ocklawaha River.

| Note | Item | Data | Units | UEV (sej/unit) | Emergy ($x10^{18}$ sej/yr) | Em$/yr ($x10^{6}$ em$) |
|---|---|---|---|---|---|---|
| Restored Condition | | | | | | |
| 1 | Ocklawaha River Flow | | | | | |
| | (a) chemical potential | 6.73E+15 | J | 9.70E+04 | 652.8 | 195.5 |
| | (b) stream ecosystem metaboli | 1.64E+08 | gC | 2.47E+09 | 0.4 | 0.1 |
| | (c) sediment flow | 3.88E+09 | gC | 7.40E+08 | 2.9 | 0.9 |
| 2 | Ocklawaha fish production | 2.00E+09 | gC | 7.80E+09 | 15.6 | 4.7 |
| 3 | Wetland production | | | | | |
| | (a) flooded area | 2.22E+10 | gC | 2.60E+08 | 5.8 | 1.7 |
| | (b) downstream wetlands | 4.73E+10 | gC | 2.60E+08 | 12.3 | 3.7 |
| | (c) upstream stressed wetlands | 1.77E+10 | gC | 2.60E+08 | 4.6 | 1.4 |
| | ***Environmental values*** | | | | ***694.4*** | ***207.9*** |
| 4 | Human Recreation (Restored river) | | | | | |
| | (a) emergy of participation | 2.51E+06 | hours | 1.10E+14 | 276.1 | 82.7 |
| | (b) economic contribution | 1.95E+07 | $ | 3.34E+12 | 65.1 | 19.5 |
| 5 | Human Recreation (Rodman Reservoir) | | | | | |
| | (a) emergy of participation | 1.04E+06 | hours | 1.10E+14 | 114.4 | 34.3 |
| | (b) economic contribution | 3.46E+06 | $ | 3.34E+12 | 11.6 | 3.5 |
| | ***Human & economic flows*** | | | | ***467.2*** | ***139.9*** |
| Restoration of Free Flowing Ocklawaha River | | | | | | |
| 6 | Partial Restoration | | | | | |
| | (a) revegetation (2000 tree/ha) | -6.07E+05 | Units | 1.65E+12 | -1 | -0.3 |
| | (b) economic cost of revegetati | -7.89E+04 | $ | 3.34E+12 | -0.3 | -0.1 |
| | (c) economic costs dam remov | -1.29E+05 | $ | 3.34E+12 | -0.4 | -0.1 |
| 7 | Operation & Maintenance | -2.34E+05 | $ | 3.34E+12 | -0.8 | -0.2 |
| | ***Economic costs*** | | | | ***-2.5*** | ***-0.7*** |
| | ***Net values of restoration*** | | | | ***1159.1*** | ***347.0*** |

Before we examine the results, I would like to show you the complete emergy evaluations for the two alternatives.

Do not worry about reading every entry in these tables.

Their purpose is not to study each individual calculation.

Rather, I want you to appreciate the level of detail required to perform a complete emergy evaluation.

Each row represents one contribution to the system—materials, fuels, labor, ecosystem processes, or environmental resources. Every input must be identified, quantified, and converted into a common unit of solar emergy.

Only after all of these individual contributions have been evaluated can they be combined to produce the summary results.

## Case Study 2 — Restoration versus Existing Infrastructure

Results of the Emergy Evaluation

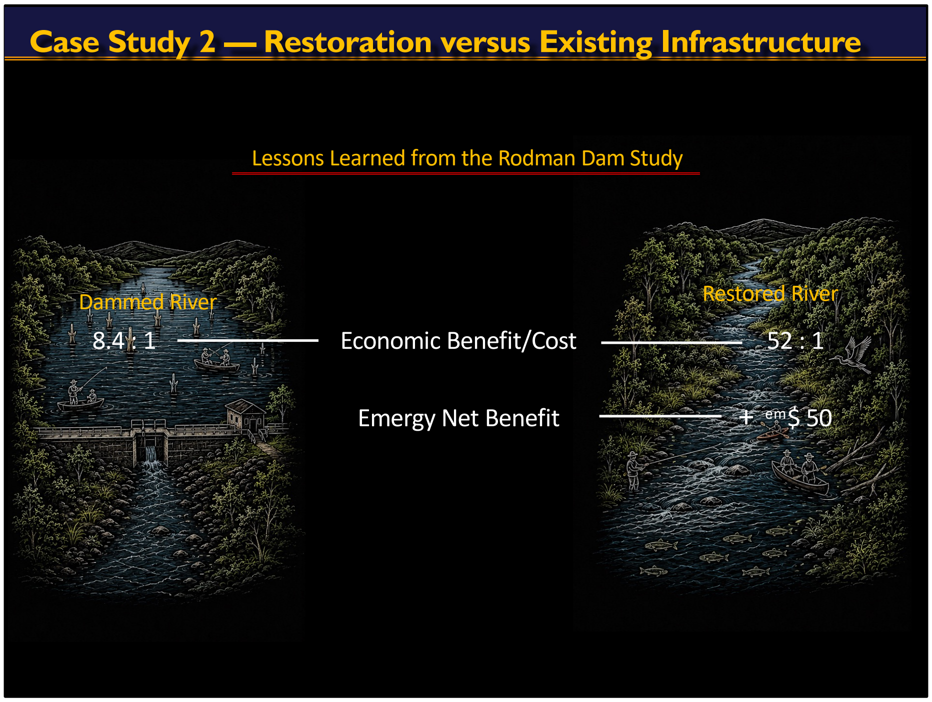
CURRENT CONDITION

| Evaluation Category | Emergy (x10$^{18}$ sej/yr) | em$/yr (million em$) |
|---|---|---|
| Environmental values | 608.8 | 182.3 |
| Human & economic flows | 390.6 | 116.9 |
| Costs of current condition | -5.7 | -1.7 |
| ***Net values of current condition*** | ***993.7*** | ***297.5*** |

PARTIAL RESTORATION

| Evaluation Category | Emergy (x10$^{18}$ sej/yr) | em$/yr (million em$) |
|---|---|---|
| Environmental values | 694.4 | 207.9 |
| Human & economic flows | 467.2 | 139.9 |
| Economic costs | -2.5 | -0.7 |
| ***Net values of restoration*** | ***1159.1*** | ***347.0*** |

The emergy evaluation shows a clear difference between the two alternatives.
When all human and ecological contributions are included, **restoring the Ocklawaha River provides approximately em$50 million per year more value than maintaining the Rodman Reservoir.**
The Rodman Dam illustrates an important principle of environmental decision making.
Neither alternative is without benefits, and neither alternative is without costs.
Maintaining the dam preserves the reservoir and the recreational opportunities it provides.
Restoring the river recovers many ecological functions that were lost when the river was impounded.
Because these benefits are so different, they cannot be compared directly using conventional economic measures alone.
Emergy provides a common accounting framework that allows both human and ecological contributions to be evaluated in the same units.
Instead of comparing dollars to ecosystem services, we compare the total emergy to support each alternative.
Perhaps the most important lesson is that restoration is not simply the removal of infrastructure. It is the replacement of one set of ecosystem services with another.
By accounting for both technological investments and ecological functions, emergy reveals the complete systems consequences of each decision.
As we have now seen in two very different case studies, the strength of emergy is not that it tells us what decision to make. Its strength is that it provides an objective biophysical basis for making better-informed decisions.




The Rodman study reaches an interesting conclusion.

From a conventional economic perspective, restoration substantially increases recreational income while reducing annual operating costs.

The benefit-cost ratio increases from approximately **8 to 1** under the current conditions to more than **50 to 1** after restoration.

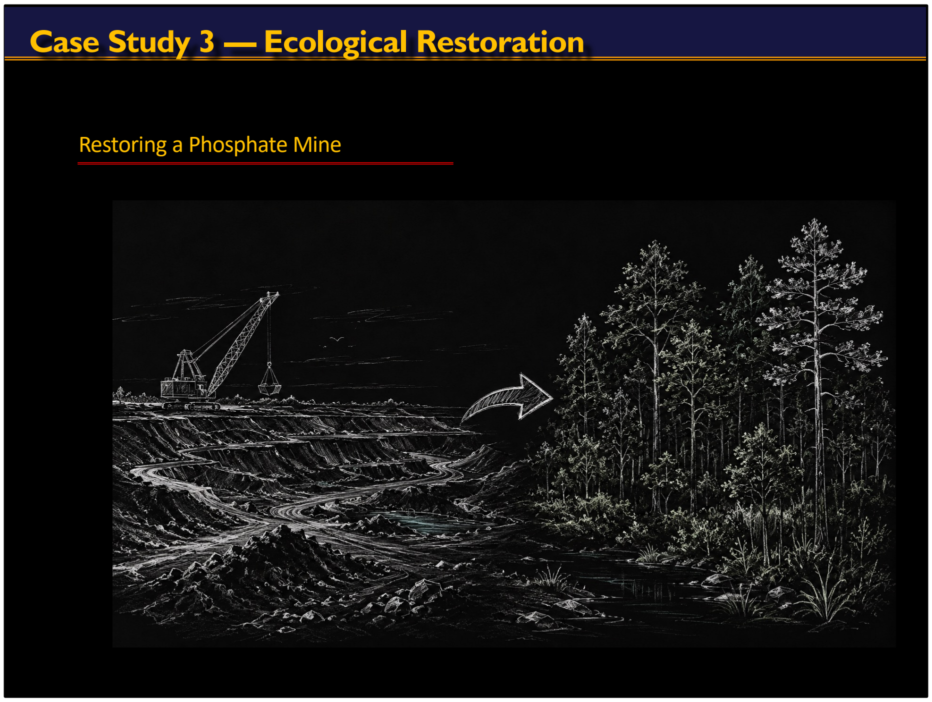
The emergy evaluation reaches a similar conclusion from a completely different perspective.

When both ecological functions and human benefits are included, restoration increases the total net value of the river system by approximately **em$50 million per year.**

The important point is not simply that restoration produces a larger total value. The important point is **why**.

Restoring the river recovers ecosystem functions that had been lost, while also increasing opportunities for recreation and reducing the long-term costs of maintaining the dam.

Together, the economic analysis and the emergy evaluation suggest that restoration provides both greater economic returns and greater total biophysical value.




Our final case study examines a very different type of environmental decision.

Unlike the previous examples, the question is whether society should invest today in restoring a landscape that has been severely altered by mining.

For more than a century, phosphate mining has supplied fertilizer for agriculture around the world. In doing so, however, mining removes the original soils and vegetation, leaving behind a landscape that has lost much of its ecological structure and function.

The goal of restoration is to rebuild that ecosystem.

As this illustration suggests, the objective is to transform a disturbed mining landscape into a self-sustaining forest capable of supporting the productivity and ecological functions of the original system.

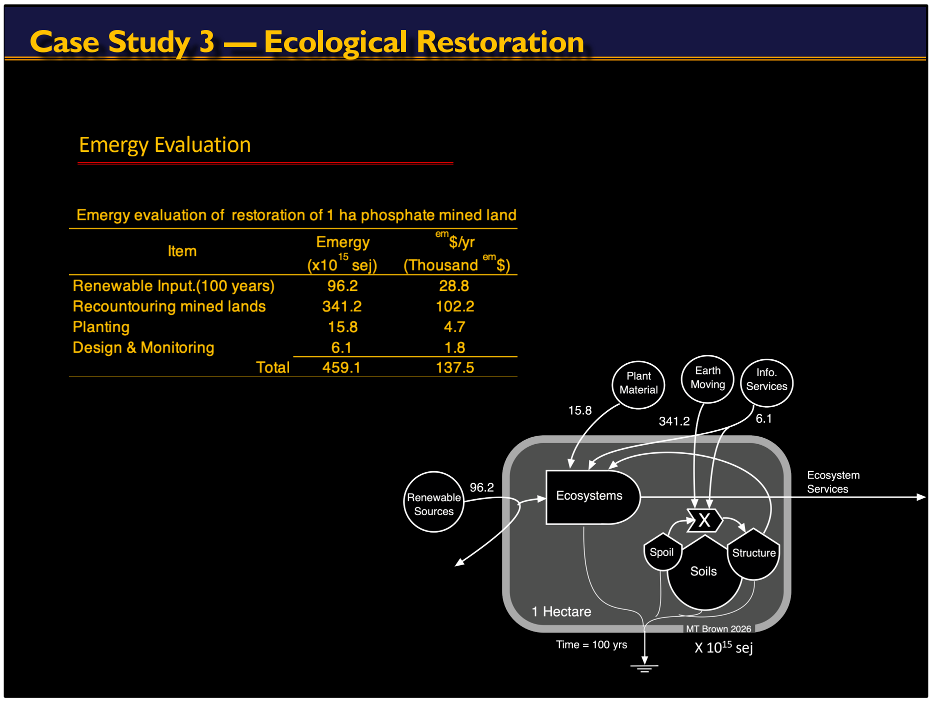
Unlike the previous case studies, however, restoration is not an immediate process.

A forest cannot simply be constructed.

It must develop through decades of ecological succession as soils improve, vegetation establishes, and ecosystem processes gradually recover.
This introduces a new challenge for emergy evaluation.

The costs of restoration occur almost entirely at the beginning of the project, while many of the ecological benefits are not realized until decades later.

The question therefore becomes not simply whether restoration is worthwhile, but whether the long-term ecological gains justify the initial investment.




| Item | Emergy ($x10^{15}$ sej) | em$/yr (Thousand em$) |
|---|---|---|
| Renewable Input.(100 years) | 96.2 | 28.8 |
| Recountouring mined lands | 341.2 | 102.2 |
| Planting | 15.8 | 4.7 |
| Design & Monitoring | 6.1 | 1.8 |
| Total | 459.1 | 137.5 |

This slide summarizes the resources required to restore one hectare of phosphate-mined land.

The task is to identily and quantify, every important input and converted into emergy before the alternatives can be evaluated.

This summary shows the results.

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The largest contribution is earthmoving and recontouring the mined landscape.

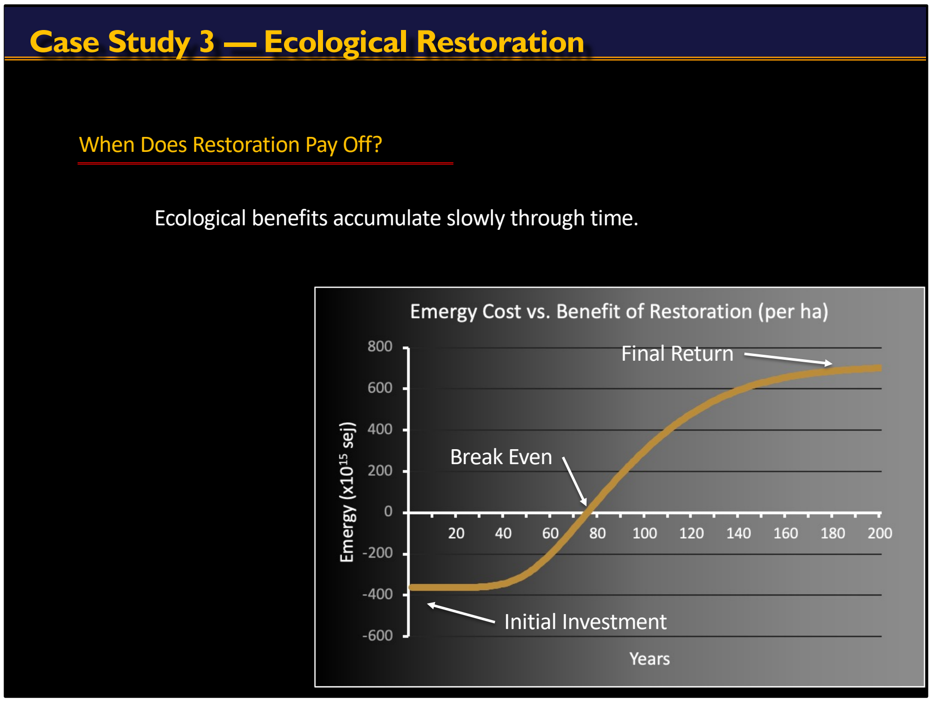
Additional investments are required for planting, together with the design and monitoring needed to guide the restoration during its early years.

Over the following century, renewable environmental inputs continue to support the development of the recovering ecosystem.

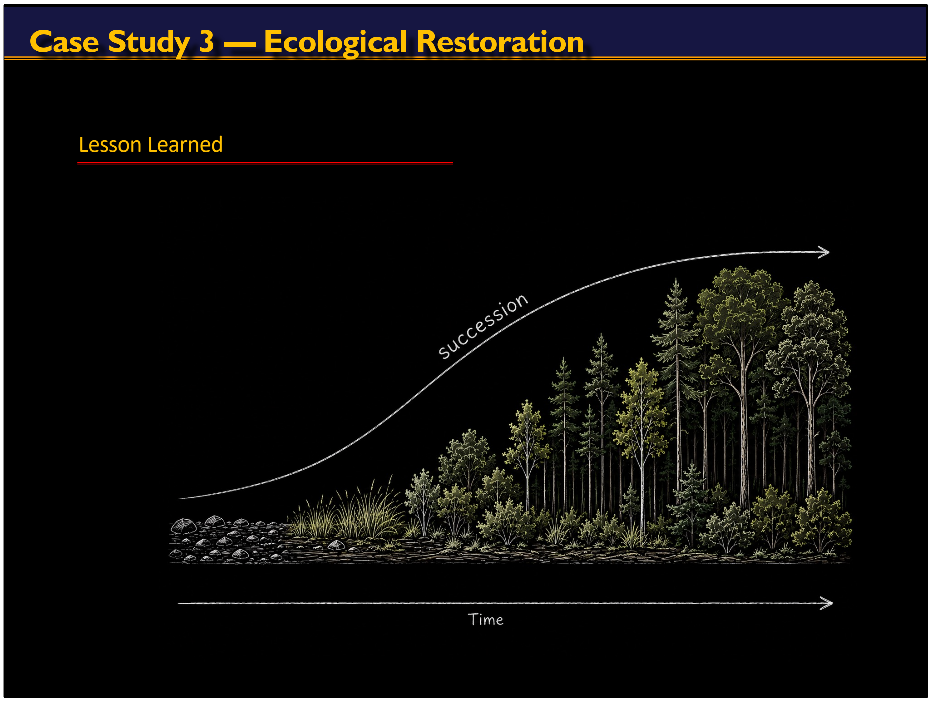
The systems diagram on the right summarizes these flows. Materials, labor, and earthmoving rebuild the physical landscape, while renewable environmental inputs gradually drive the development of soils, vegetation, and ecosystem structure.

As the ecosystem matures, it begins to generate the ecological functions and services that restoration is intended to recover.

The important observation is that the costs are concentrated at the beginning of the project, while the benefits develop gradually over many decades.




This figure illustrates the long-term return on the restoration investment.
At the beginning of the project, the balance is strongly negative because nearly all of the costs occur immediately.
Earthmoving, planting, and the early years of management require a substantial investment of energy, materials, labor, and information.
At first, there is very little return.
The newly restored landscape is only beginning its ecological recovery.
As ecological succession proceeds, the system begins to generate increasing benefits. Forest biomass accumulates, primary productivity increases, soils improve, and the restored ecosystem provides progressively more ecological services.
Notice that the curve crosses the break-even point after about **75 years**.
At that point, the cumulative ecological benefits have repaid the original restoration investment.
The benefits continue to accumulate long after the investment has been recovered.
After approximately **200 years**, the cumulative emergy benefit is nearly **three times greater** than the original restoration cost, corresponding to a benefit-to-cost ratio of about **3 to 1**.
This example teaches an important lesson about environmental decision making.
Many restoration projects appear expensive when viewed over only a few years.
But ecosystems develop on much longer timescales than human projects or political cycles..




Ecosystems do not recover overnight.

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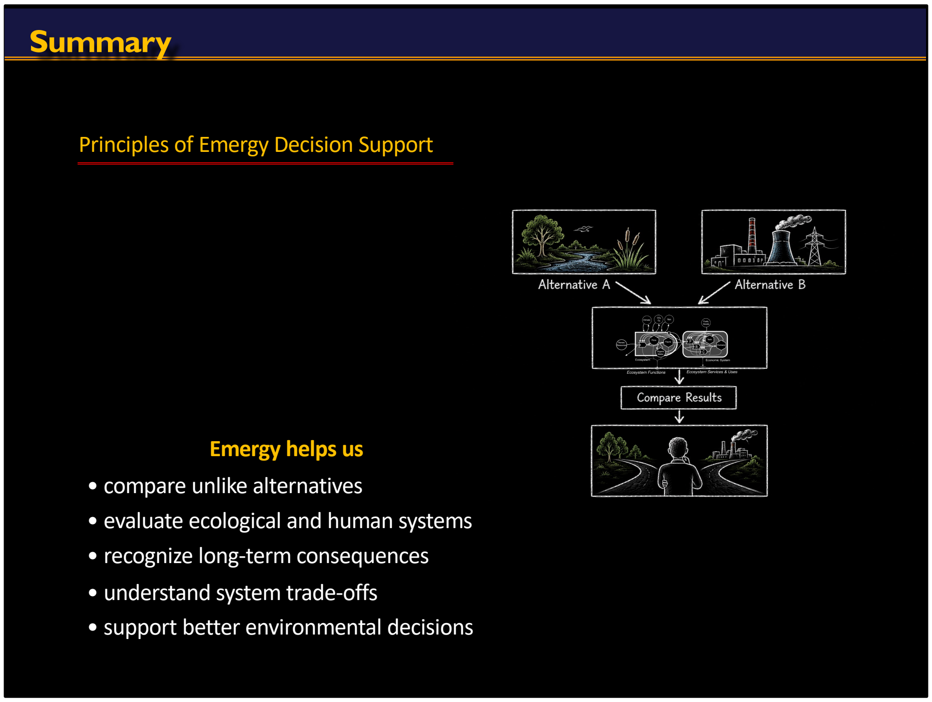



Let us conclude by returning to the question we asked at the beginning of this lecture. **How do we decide which alternative is better?**

Throughout this course we have learned that environmental decisions are rarely simple. Every alternative involves trade-offs among ecological functions, human benefits, economic costs, and long-term sustainability.

Emergy does not eliminate those trade-offs, nor does it make the decision for us. Instead, it provides a common biophysical accounting framework that allows very different alternatives to be evaluated on the same basis.

In this lecture we examined three examples.

The Crystal River study showed that replacing natural ecosystem functions with engineered technology may require very large resource investments.

The Rodman Dam study demonstrated that restoration decisions must account for both ecological and human benefits when comparing alternative futures.

Finally, the phosphate restoration study reminded us that ecosystems recover over decades, and that environmental investments must be evaluated over appropriate time horizons.

Although these case studies addressed very different problems, they all followed the same decision process.

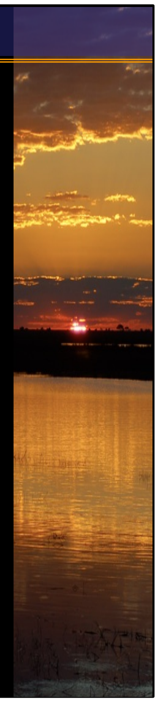
First, define the alternatives. Then identify all significant environmental, economic, and human contributions.

Evaluate each alternative using the same emergy accounting framework. Finally, compare the results and interpret the trade-offs.

This is the central contribution of emergy to environmental decision making.

It allows us to think like systems scientists by evaluating the complete biophysical consequences of alternative actions before deciding which path to follow.

## Thank You…



Thank You for Your Attention

感谢您的聆听