2026 International Summer Course on Environmental and Ecological System Engineering

Part A: Environmental Accounting and Systems Thinking (EAST)

Lecture 9:

Emergy & Environmental Impact Assessment

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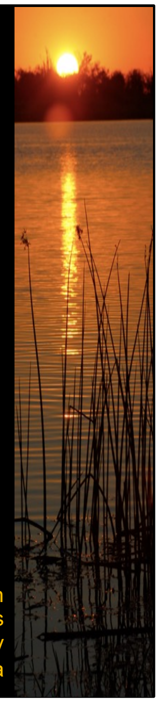


In this lecture we study environmental impact assessment.

Organization…

We begin by defining organization.

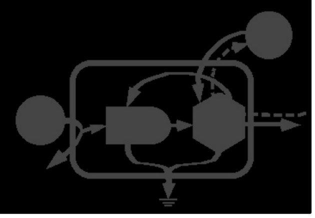
Then show that environmental impacts are changes in organization.

Next distinguish ordering and disordering emergy.

Introduce pulse disturbances.

Show how emergy measures those changes.

Predictive environmental assessment using LDI as a planning tool.



We need to ask a simple question.

What is an environmental impact?

At first glance, the answer seems obvious. A forest is cleared. A road is built. A wetland is drained. A river is dammed.

But these are simply activities. They describe what people do, not necessarily what changes in the environment.

Traditional environmental assessments often list impacts such as habitat loss, pollution, soil erosion, reduced biodiversity, and changes in water quality.

These are all important observations, but they do not explain what these impacts have in common.

From a systems perspective, every environmental impact begins with a change in the way energy, materials, and information move through a system.

Trees, animals, soil, water, and people are the visible components of a much larger network of interactions.

When those interactions change, the organization of the system changes.

A system is much more than a collection of individual parts.

It is the arrangement of those parts and the interactions between them.

i.e. Organization.

Organization is what transforms a collection of components into a functioning system.

Environmental impacts are important because they alter that organization.

Organization does not appear spontaneously, nor does it maintain itself.

Every organized system requires a continuous supply of environmental support.

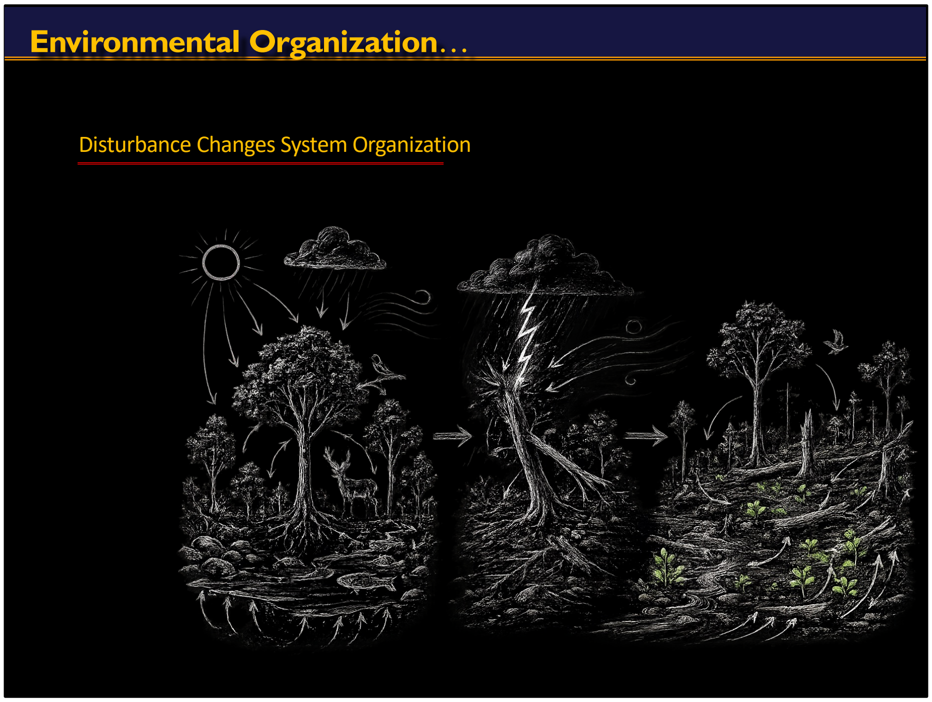
Sunlight, rain, wind, groundwater, and nutrients continually sustain the pathways through which energy, materials, and information move.

In emergy terminology, these are **ordering emergy flows**.

They do more than supply energy. They continually build and maintain environmental organization.

Without this continuous support, organization gradually breaks down.

But What happens when an external disturbance overwhelms these ordering processes?



Environmental systems are continually exposed to disturbances.

Storms, floods, fires, earthquakes, volcanic eruptions, and human activities all introduce energy into organized systems.

These disturbances do more than remove trees or buildings.

They alter the pathways through which energy, materials, and information move.

A **pulse disordering event** occurs when an external energy input exceeds what the system has evolved, or been designed, to withstand.

Organization begins to break down.

From a systems perspective, environmental systems are continually influenced by two opposing processes.

Ordering emergy builds and maintains organization.

Disordering emergy reduces organization.

Not every disturbance has the same effect. The importance of a disturbance depends on its magnitude.

Disturbances are a natural part of every environmental system.

Environmental impacts do not arise simply because energy enters a system.

They occur when the magnitude, frequency, or duration of a disturbance exceeds the conditions to which the system has become adapted.

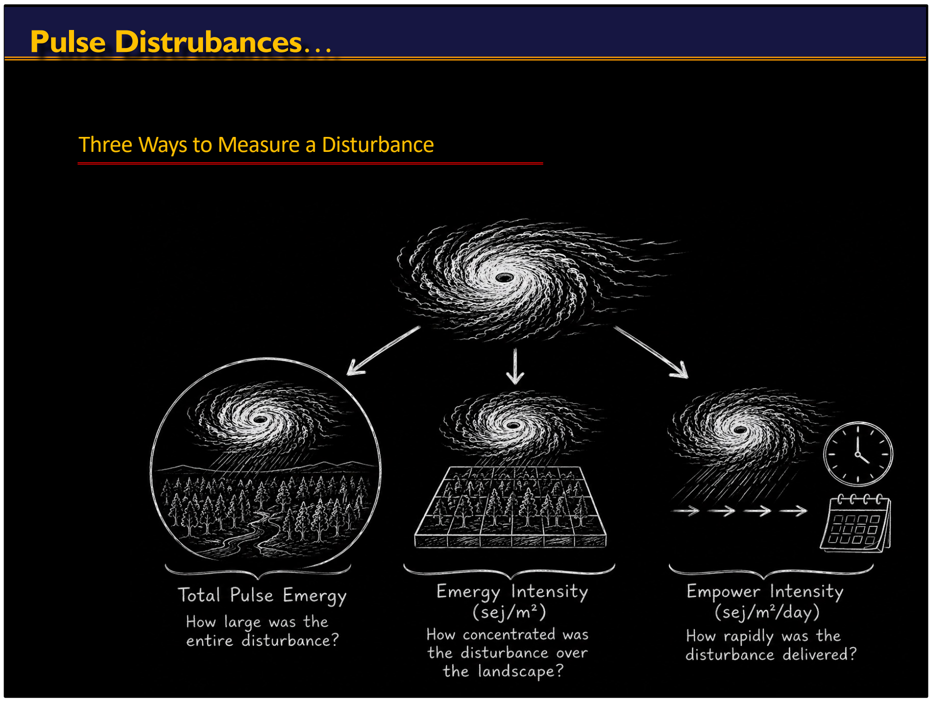
A gentle wind may bend branches without changing the organization of a forest.

A stronger storm may remove branches or individual trees while leaving the overall structure largely intact.

A hurricane, however, can reorganize an entire landscape within a few hours.

Environmental impact therefore depends not only on the magnitude of the disturbance, but also on the extent to which it alters system organization.

A hurricane is an example of what we call a pulse disturbance—a relatively short-lived event that delivers a large amount of energy in a brief period of time.



Once we identify a pulse disturbance, the next question is how to describe its magnitude.

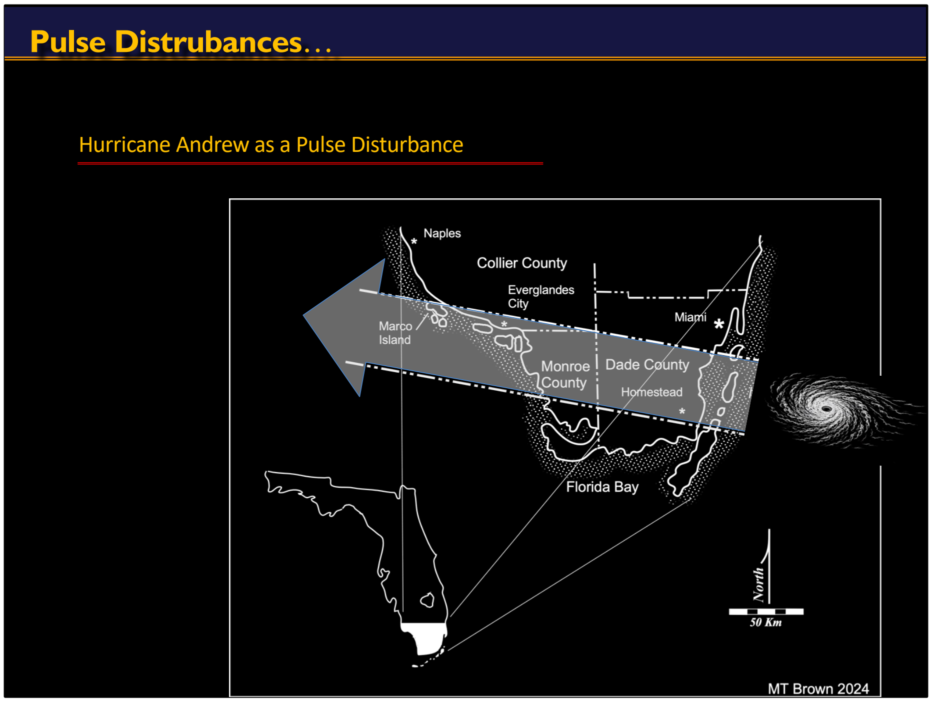
three complementary measures.

The first is **total pulse emergy**,
which represents the total emergy delivered by the disturbance.

The second is **pulse emergy intensity**, expressed as emergy per unit area.
This describes how concentrated the disturbance is across the landscape.

The third is **pulse empower intensity**, expressed as emergy per unit area per unit time.
This describes how rapidly the disturbance is delivered.

Together, these three measures provide a much more complete description of a pulse disturbance than any single measure alone.



Hurricane Andrew provides an excellent example of a pulse disturbance.

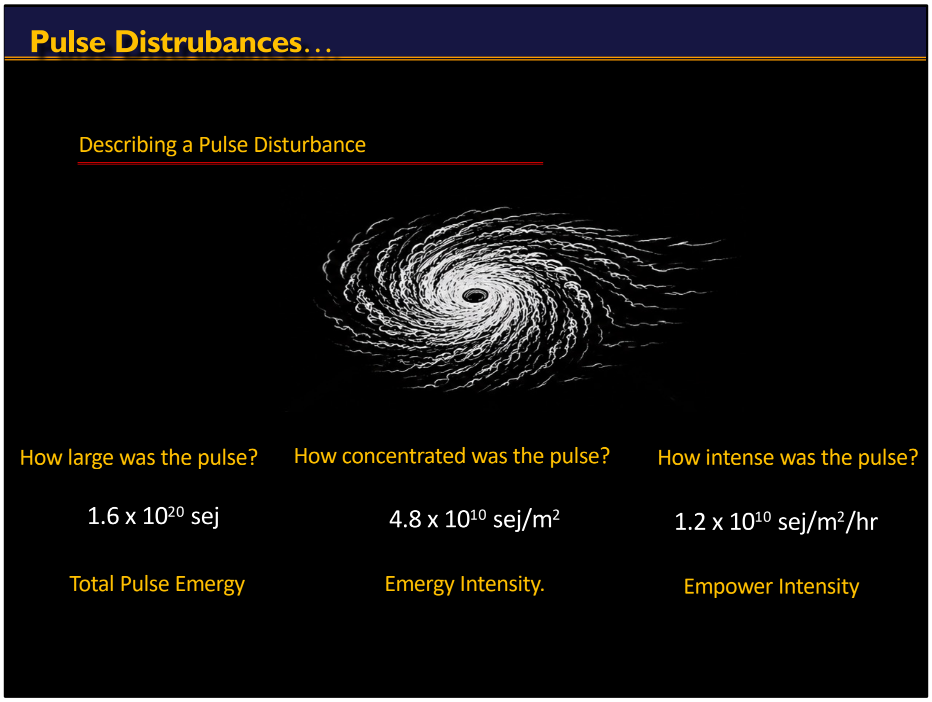
In August 1992, Andrew crossed southern Florida with sustained winds of 165 miles per hour.

The storm passed through the impact area in only a few hours, delivering a large pulse of available energy to both natural and human systems.

Using the three measures we have just introduced, we can now describe the hurricane quantitatively.

We can measure its total pulse emergy, its emergy intensity, and its pulse empower intensity.

These three measures describe the size of the disturbance, how concentrated it was across the landscape, and how rapidly the pulse was delivered.



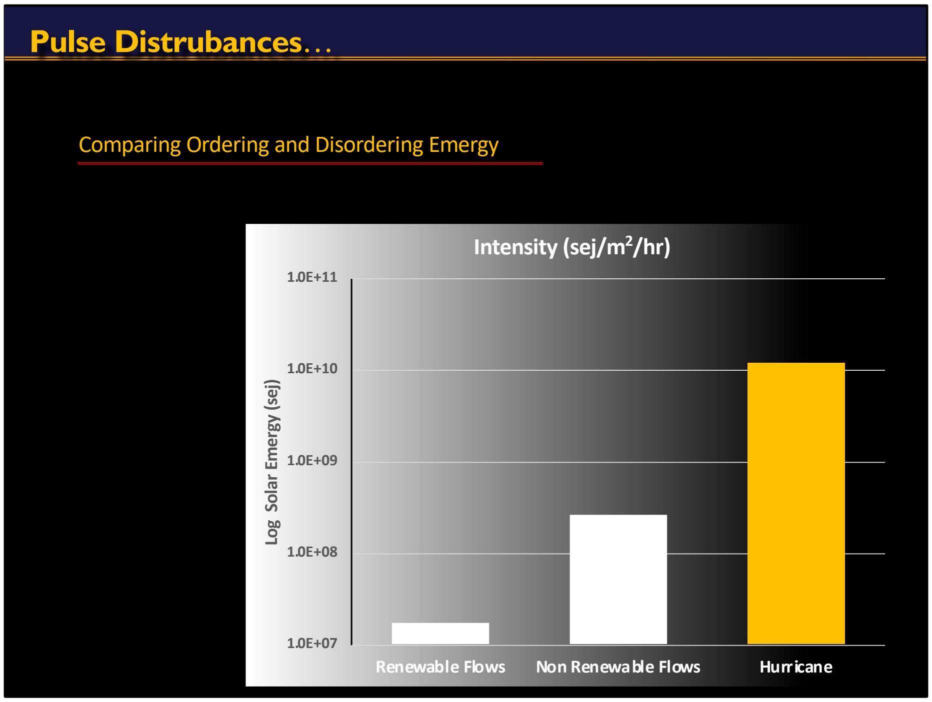
The total pulse emergy tells us the overall size of the disturbance.

Emergy intensity tells us how concentrated the disturbance was across the affected landscape.

Pulse empower intensity tells us how rapidly that emergy was delivered.

By themselves, however, these values tell us very little

Their significance becomes clear only when they are compared with the normal ordering emergy supporting the region.



The hurricane delivered its energy in only about four hours.

To make a meaningful comparison, the normal ordering emergy supporting the region must be expressed over the same four-hour period.

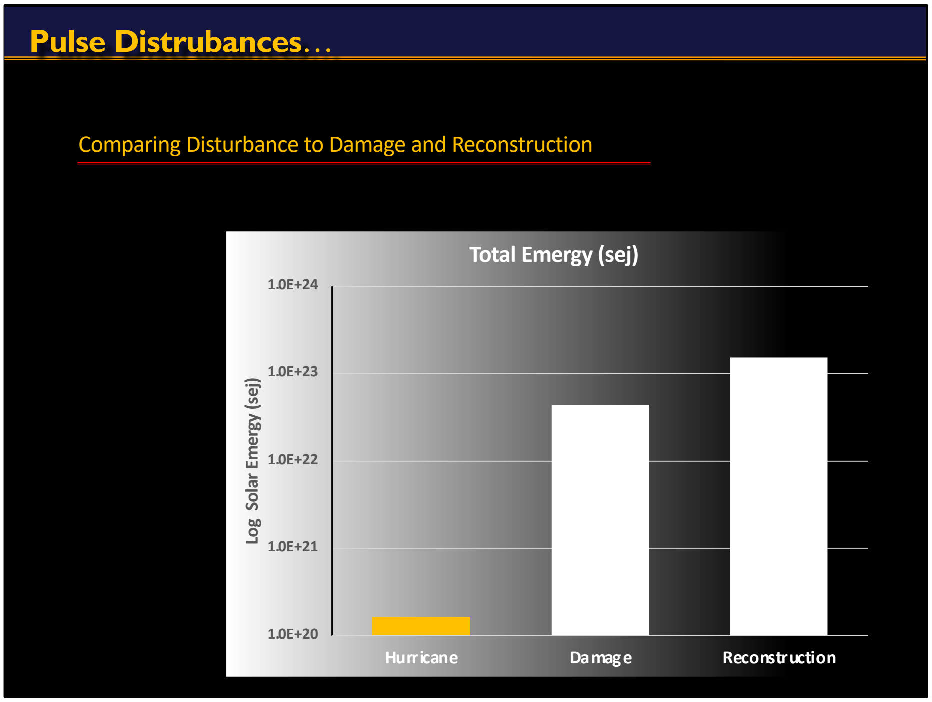
When both are placed on the same time scale, the hurricane pulse becomes more than forty times greater than the next largest emergy input.

This illustrates an important principle of emergy accounting.

Ordering and disordering emergy must be compared over the same time interval.

It also helps explain why pulse disturbances can dramatically reorganize environmental systems.

For a brief period, the disordering pulse overwhelms the normal ordering processes that maintain system organization.



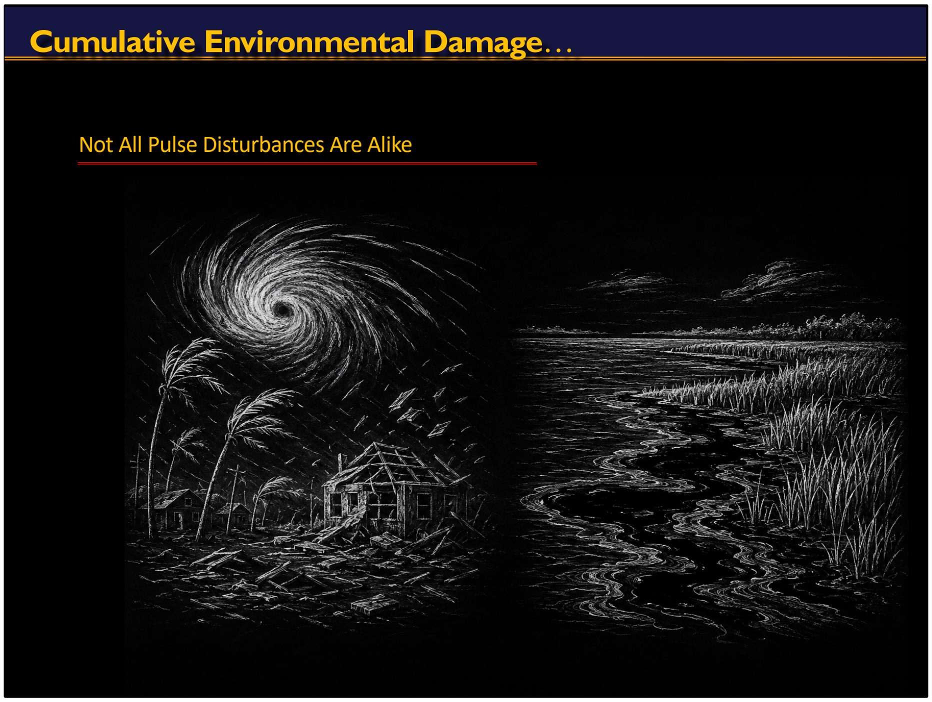
A pulse disturbance represents only the energy that initiates environmental change. The resulting damages can be many times larger than the emergy contained in the disturbance itself.

In Hurricane Andrew, the total damages amounted to almost 270 times the emergy of the hurricane itself.

Recovery required an even larger investment of emergy.

The labor, materials, energy, and services used to rebuild exceeded 900 times the emergy of the hurricane and more than three times the damages.

This illustrates that a relatively small pulse of disordering emergy can trigger a much larger flow of ordering emergy as natural and human systems reorganize.



Hurricanes are only one type of pulse disturbance.

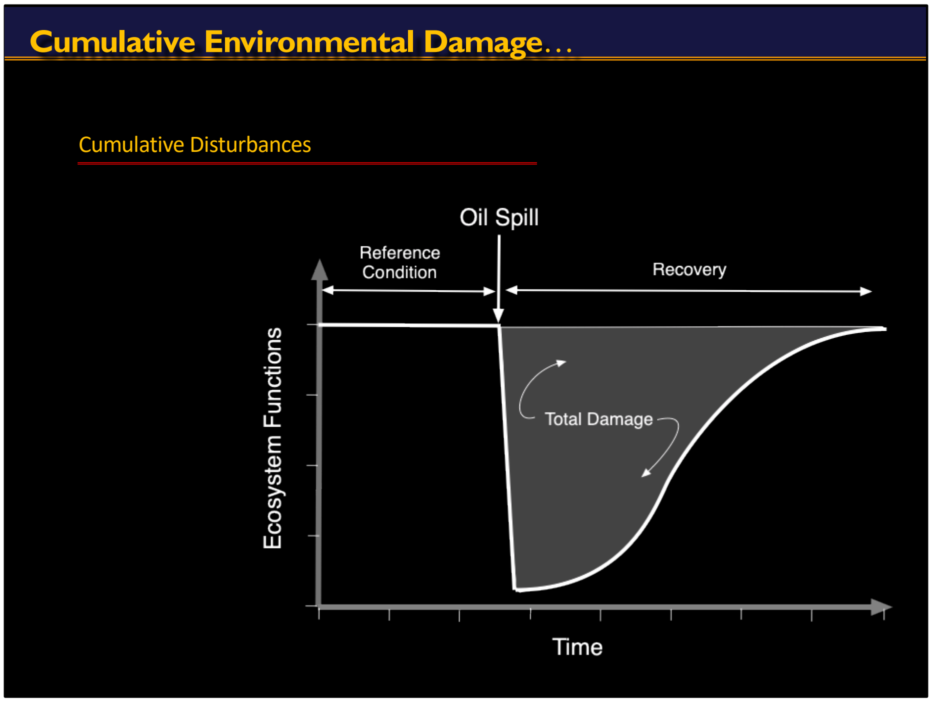
Different disturbances reorganize environmental systems in different ways.

A hurricane primarily damages physical structure.

An oil spill introduces contaminants that disrupt ecological processes.

Although the mechanisms differ, the common objective remains the same: to evaluate the environmental consequences of the disturbance.

We now turn to an example in which the emphasis is not on the pulse itself, but on the environmental damages it produces.



Unlike a hurricane, where the pulse disturbance is the primary focus, an oil spill produces environmental damage that continues long after the initial event.

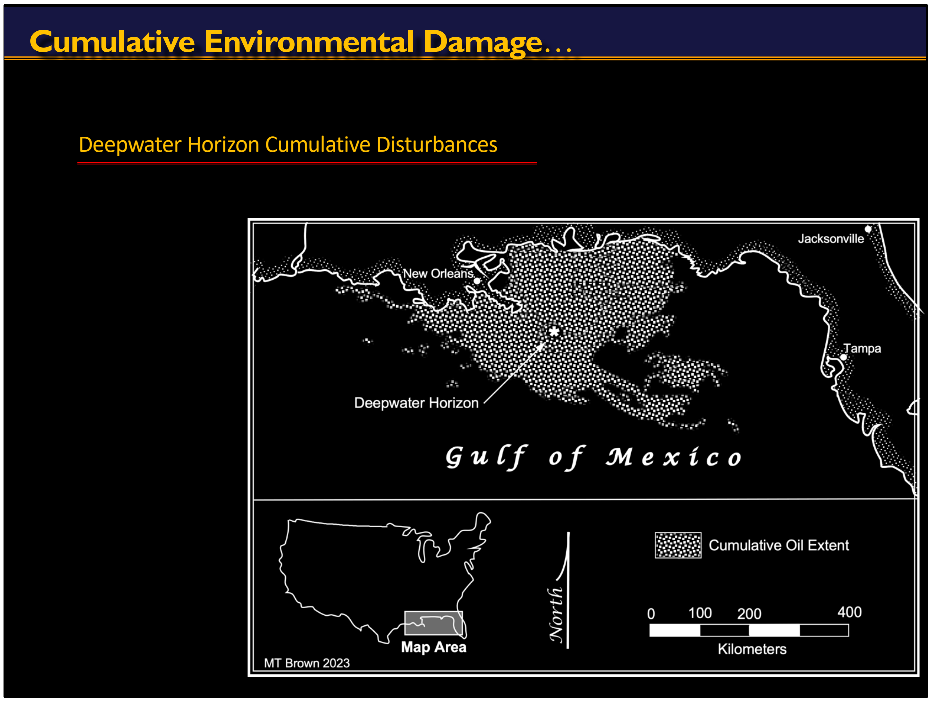
Some organisms die immediately, but many ecosystem processes remain below their reference condition for years..

The environmental damage is therefore not simply the immediate loss of plants and animals.

It is the cumulative loss of ecosystem function during the entire recovery period.

Because different ecosystem components recover at different rates, these cumulative losses cannot usually be estimated from field observations alone.

Estimating this cumulative loss requires a dynamic ecosystem model capable of simulating recovery through time.



The Deepwater Horizon blowout released oil into the Gulf of Mexico for nearly three months.

The oil contaminated extensive areas of coastal wetlands along the northern Gulf of Mexico.

Our study focused on the coastal marsh ecosystem because of its ecological importance and the availability of long-term ecological data.

The objective was to estimate the cumulative environmental damages to that ecosystem over the entire recovery period.

Cumulative Environmental Damage…

Deepwater Horizon Cumulative Disturbance (20 years)

Compartment	Net Difference (gC/m2)	UEV sej/gC	Emergy ($x10^{12}$ sej/ha)	Emdollars (^{em}\$/ha)
Algae	-5.0	2.78E+08	-13.8	-4.1
Spartina	-3.9	1.95E+10	-762.4	-228.3
Juncus	-9.5	6.06E+09	-573.7	-171.8
Crabs/Shrimp	-43.2	3.48E+10	-15,041.7	-4,503.5
MacroInverts	5.8	4.91E+09	286.7	85.8
Insects	-57.8	1.94E+10	-11,213.8	-3,357.4
Mammals	-59.7	3.23E+11	-192,893.3	-57,752.5
Fish	0.9	2.33E+10	212.6	63.6
Birds	-5.4	2.37E+11	-12,694.1	-3,800.6
Detritus	44.4	1.60E+09	709.0	212.3
		Total	-231,984.5	-69,456.4

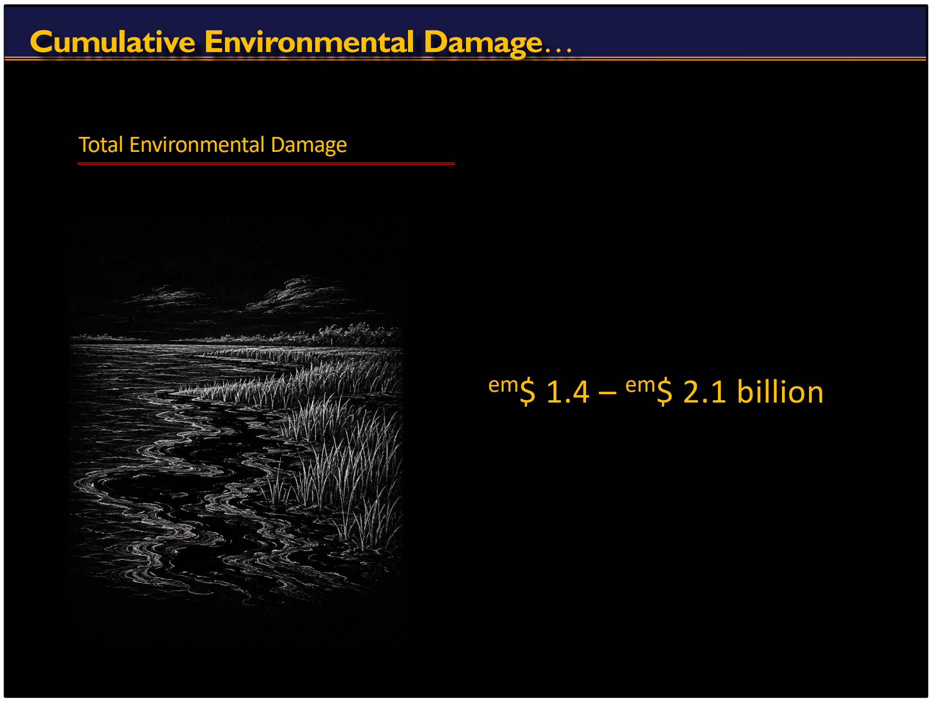
We developed a simulation model of the marsh system that contained all these compartments.

And simulated the oiling event and the recovery until the processes and biomass of components had recovered ABOUT 20 years

Once the cumulative changes in each ecosystem component were been estimated over the recovery periodwe converted them to emergy using their unit emergy values.

As in previous emergy evaluations, the contributions from each component are summed to obtain the total environmental damage.

The final column expresses those damages in emdollars, allowing the results to be interpreted within a policy and decision-making framework.

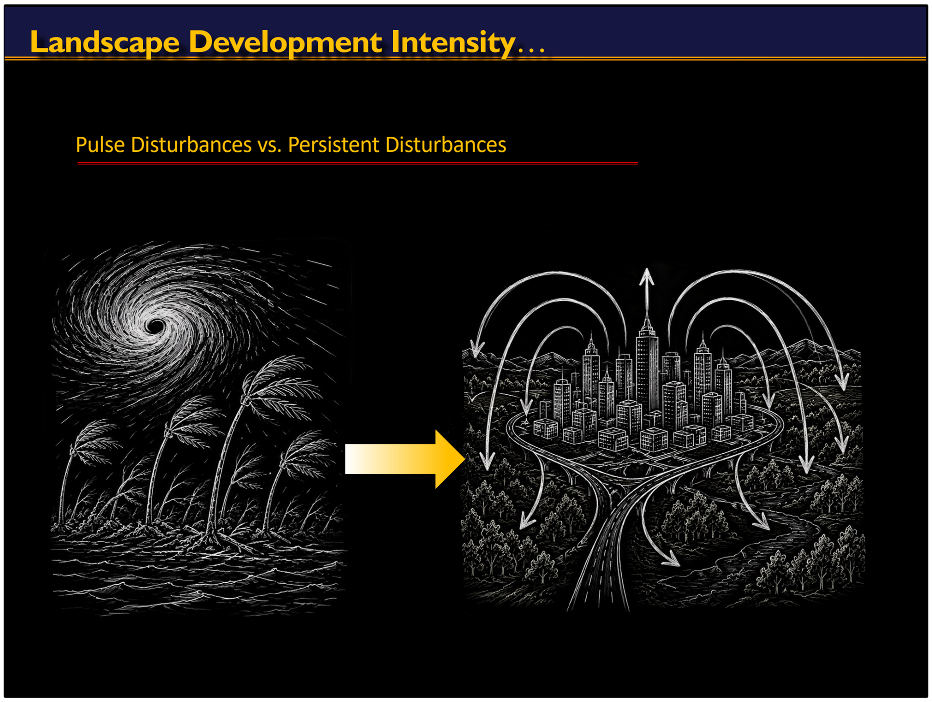


The affected coastal marsh covered between 200 and 300 square kilometers.

Applying the cumulative damage estimates to that area yielded a total environmental loss between 1.4 and 2.1 billion emdollars.

Unlike conventional economic assessments, these values represent the cumulative loss of ecosystem organization during recovery, expressed in emergy units.

They provide a biophysical measure of environmental damages



So far we have examined pulse disturbances.

Hurricanes and oil spills begin as relatively short-lived events.

Although their damages may persist for years, the disturbance itself eventually ends.

Many human activities are fundamentally different.

Urban development, highways, agriculture, and industry create persistent disturbances that continually influence the surrounding landscape.

Instead of asking how large a pulse was, we now ask a different question.

How can we evaluate the long-term influence of persistent land uses on surrounding ecosystems?

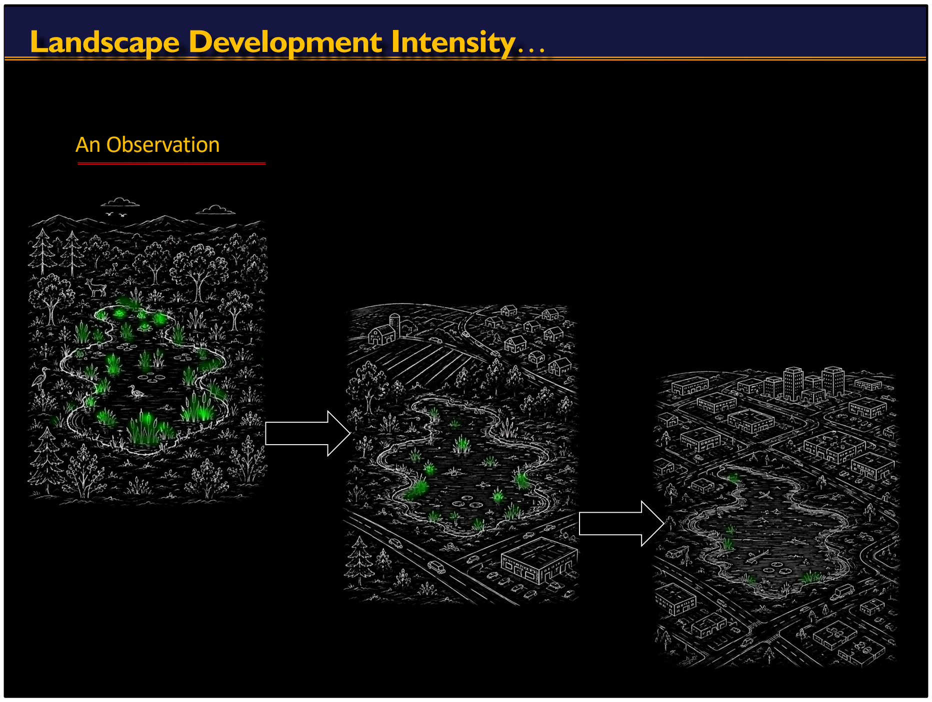
Human land uses such as cities, highways, agriculture, and industry continually influence the ecosystems around them.

These influences are numerous and often occur simultaneously.

They include habitat fragmentation, altered hydrology, pollution, invasive species, and many other interacting processes.

Measuring each of these influences individually is difficult.

Instead, we ask whether there is a way to evaluate their combined effect on the surrounding landscape.



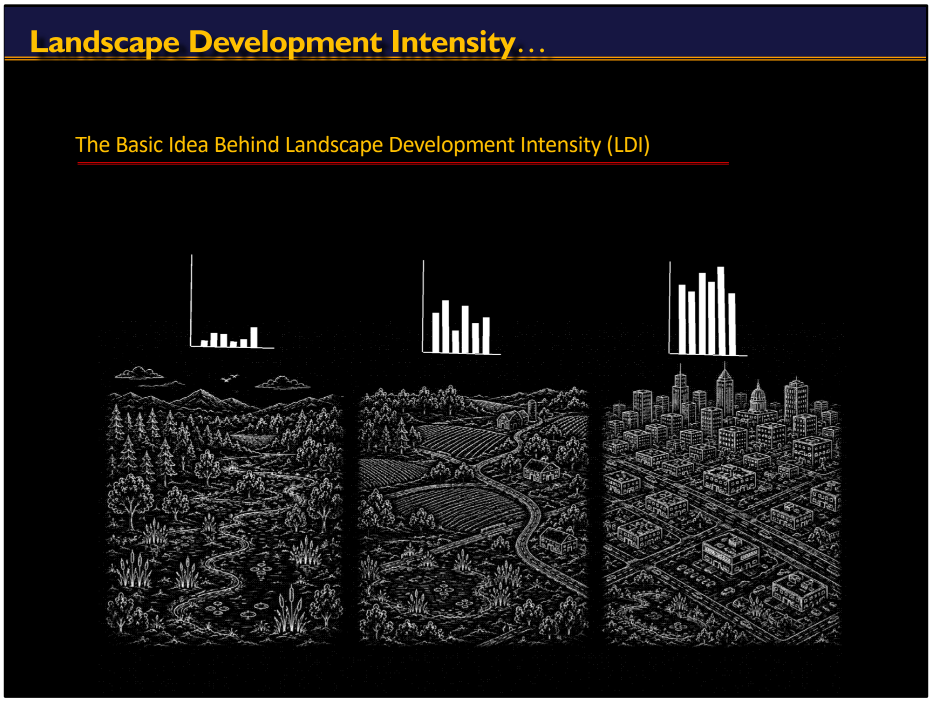
Over many years of field work in Florida, I noticed a remarkably consistent pattern.

As natural ecosystems became surrounded by increasingly intensive human land uses, their ecological condition generally declined.

The causes were numerous and often difficult to separate, yet the overall pattern remained remarkably consistent.

This suggested that the **intensity of the surrounding land use** might provide an integrated measure of long-term ecological disturbance.

The challenge was to find a way to quantify that relationship.



The next question is how to quantify land use intensity

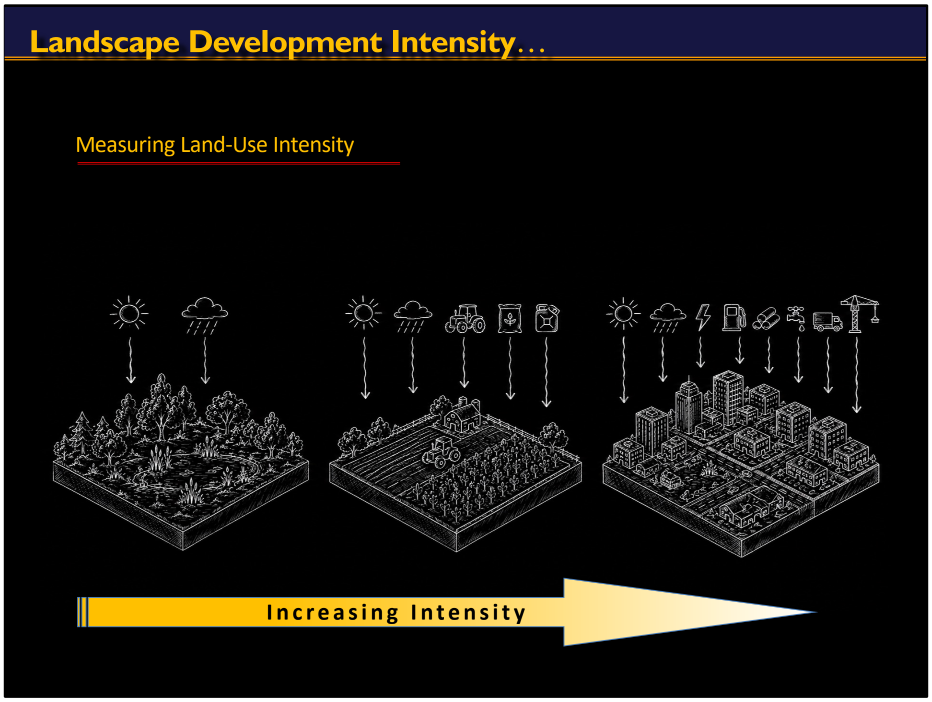
Simply counting the area of roads, buildings, or agriculture is not sufficient because different land uses require very different levels of human activity to create and maintain.

A natural forest depends almost entirely on renewable environmental inputs.

An developed land uses, by contrast, require continuous inputs of fuels, electricity, materials, labor, and services.

These supporting inputs can all be expressed as **areal empower intensity**, the annual emergy flow required to support one unit area of land.

The Landscape Development Intensity, or LDI, uses these areal empower intensities to represent the long-term disturbance associated with different land uses.



The intensity of a land use depends on the amount of emergy required to create and maintain it.

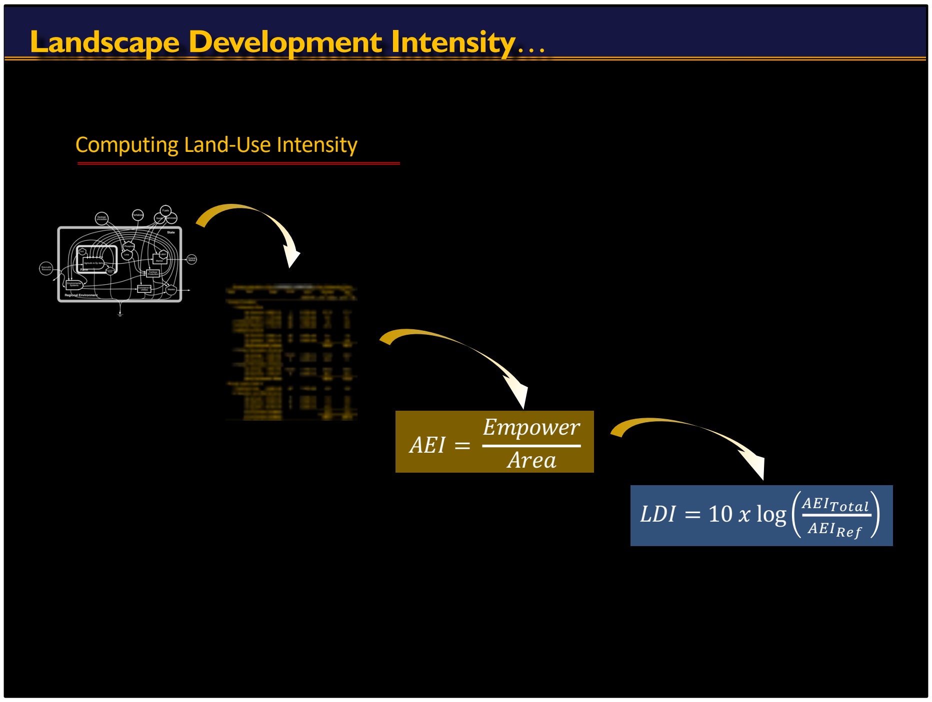
A natural forest is supported primarily by renewable environmental inputs.

Agricultural lands require additional human inputs such as machinery, fuels, fertilizers, and labor.

Urban areas require even greater continuous inputs of energy, materials, infrastructure, and services.

By expressing these inputs on an area basis, we obtain the **areal empower intensity** of each land use.

This provides a common biophysical measure of land-use intensity that can be compared across very different types of development.



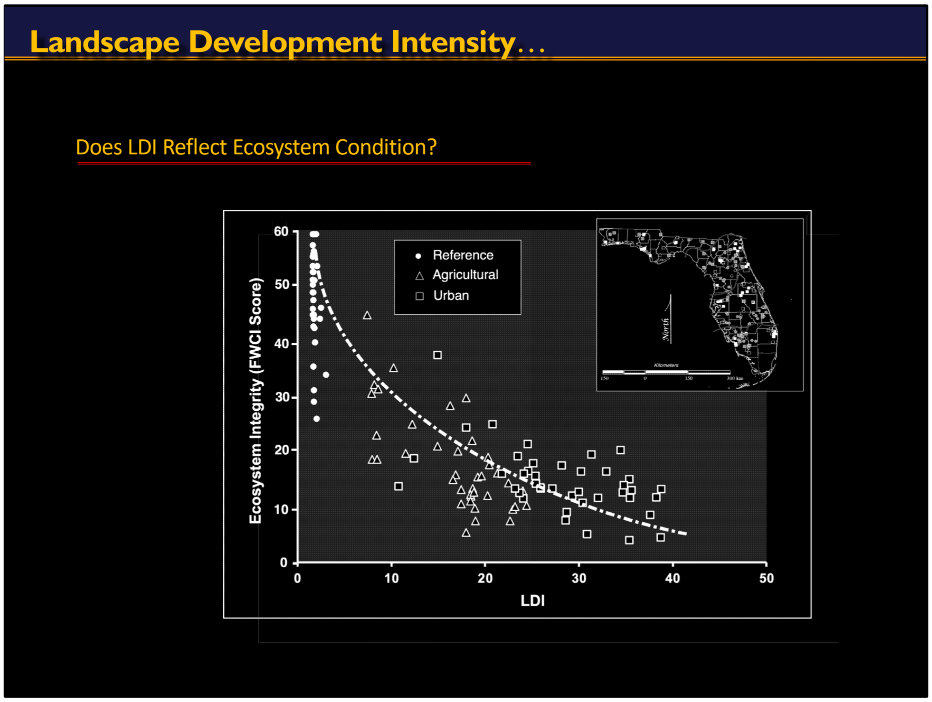
We have already learned how to evaluate individual systems using emergy accounting.

An emergy evaluation provides the annual empower supporting a particular land use.

Dividing that empower by the area occupied by the land use gives its **areal empower intensity**, or AEI.

The Landscape Development Intensity is then calculated by combining the AEIs of the different land uses that make up the landscape.

In this way, detailed emergy evaluations are translated into a single measure of persistent landscape disturbance.



This is called the Landscape Development Intensity index,

but an important question remains.

Does it actually reflect the condition of real ecosystems?

To answer that question, we compared LDI values with independent field measurements of wetland condition collected throughout Florida.

The graph shows a clear pattern.

Wetlands surrounded by landscapes with low LDI values generally have high ecological integrity.

As the development intensity of the surrounding landscape increases, measures of ecosystem integrity steadily decline.

Although individual wetlands vary, the overall relationship is remarkably strong.

This demonstrates that LDI provides a useful integrated measure of the long-term influence of surrounding land use on ecosystem condition.

Although the overall relationship between LDI and ecosystem condition is strong, individual wetlands do not all respond in exactly the same way.

Two important factors help explain this variation.

The first is **time**.

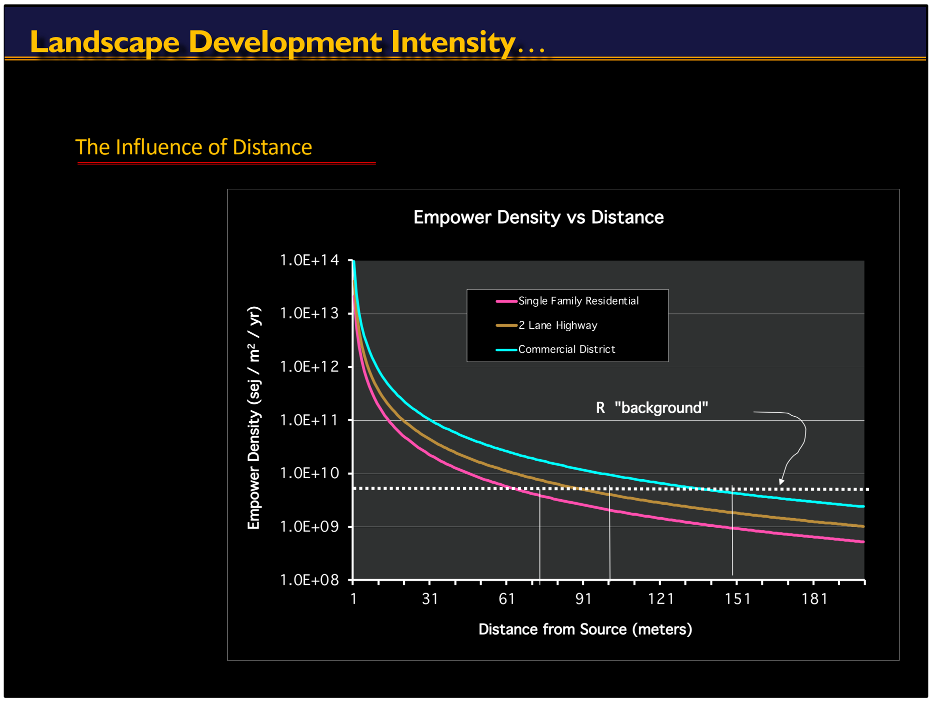
Persistent disturbances often require years before their full ecological effects become apparent.

A recently developed landscape may therefore have a higher ecological condition than its long-term LDI would eventually predict.

The second factor is **distance**.

Land uses located immediately adjacent to an ecosystem generally exert a greater influence than identical land uses located farther away.

These two factors explain much of the variation observed around the overall LDI relationship.



We have seen that LDI provides a useful measure of the long-term influence of surrounding land uses on ecosystem condition.

One additional factor, however, must also be considered.

Distance matters.

A highway immediately adjacent to a wetland will generally have a much greater ecological influence than the same highway located several hundred meters away.

The graph illustrates this relationship.

The influence of a land use is greatest near its source and decreases rapidly with increasing distance until it approaches the background level of the surrounding landscape.

Different land uses decline at different rates. More intensive developments generally exert their influence over greater distances than less intensive land uses.

Incorporating this distance-decay relationship provides a more realistic representation of how persistent disturbances affect surrounding ecosystems.

Up to this point, we have used emergy to evaluate environmental disturbances that have already occurred.

Environmental impact assessment asks a different question.

What are the likely environmental consequences before construction even begins?

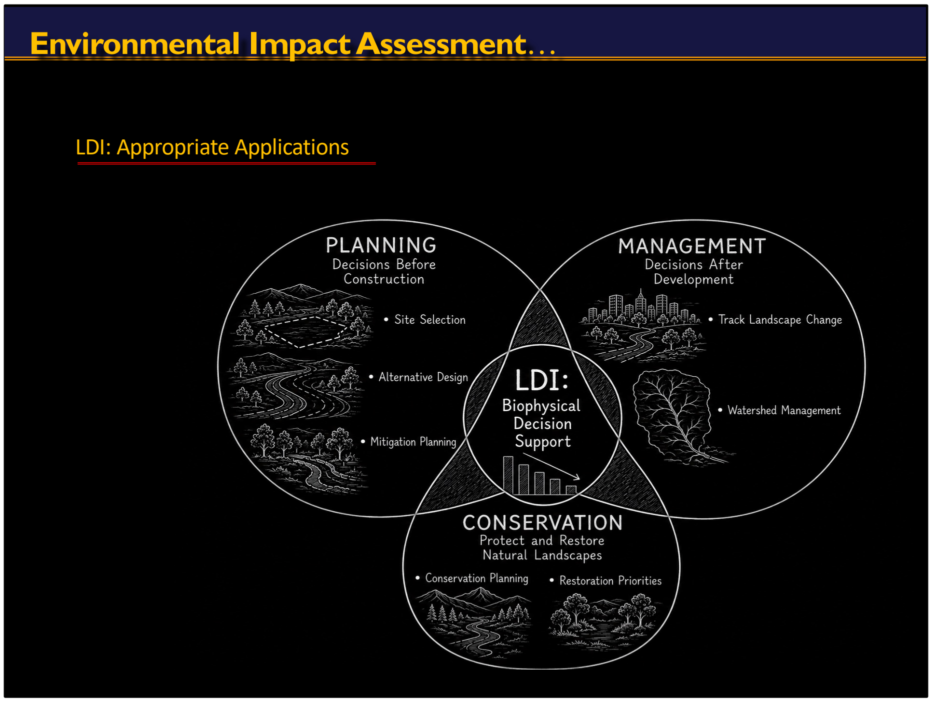
The existing landscape is first evaluated to establish its current Landscape Development Intensity.

The proposed project is then added to the landscape, and the LDI is recalculated to represent the future condition of the site.

The difference between these two evaluations provides an estimate of the additional persistent disturbance that the proposed development is expected to create.

This estimate does not predict the response of every individual species or ecosystem process. Rather, it provides an integrated biophysical measure of the long-term influence of the development on the surrounding landscape.

Because the evaluation is performed before construction begins, alternative project designs, locations, or layouts can be compared, and mitigation measures can be incorporated into the design before environmental impacts occur.



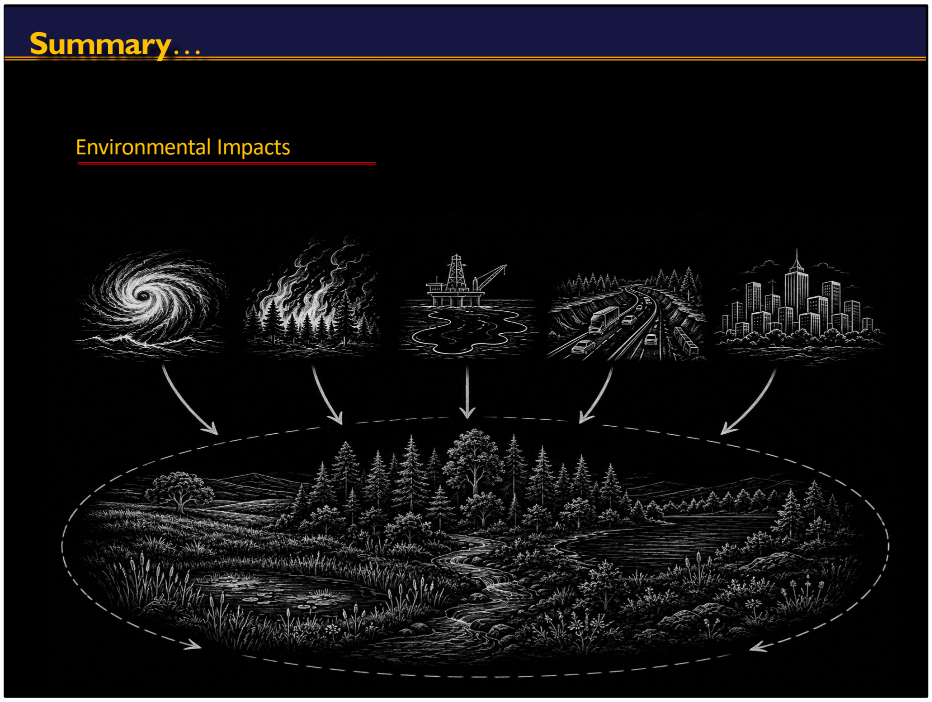
Throughout this lecture we have focused on evaluating environmental impacts. The Landscape Development Intensity extends those concepts into environmental decision making.

The first application is **planning**. Before construction begins, LDI can be used to compare alternative sites, evaluate different project designs, and identify opportunities to reduce environmental impacts through mitigation.

A second application is **management**. By evaluating changes in LDI through time, planners and resource managers can monitor landscape change, identify areas undergoing increasing development pressure, and prioritize management actions.

The third application is **conservation**. LDI helps identify landscapes that remain relatively undisturbed, evaluate the condition of surrounding ecosystems, and guide decisions about protection and restoration.

These applications are closely connected. Effective environmental planning depends on good management, and both contribute to long-term conservation. Together, they provide a biophysical framework for making informed environmental decisions using the common language of emergy.



Throughout this lecture we have viewed environmental impacts from a systems perspective.

Rather than measuring only pollutants, damaged habitats, or economic losses, emergy asks a broader question:

How has human activity changed the organization of natural systems?

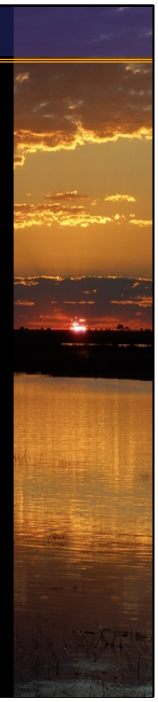
We saw that pulse disturbances can be evaluated by their magnitude, intensity, and duration, while persistent land-use disturbances can be evaluated using Landscape Development Intensity.

Together, these methods provide a common biophysical framework for understanding environmental impacts across many different scales and types of disturbance.

Most importantly, they allow environmental impacts to be evaluated not only after they occur, but also before development begins, helping planners compare alternatives and make better environmental decisions.

Emergy provides a common language for understanding how human activities reshape the natural world.

Thank You…



Thank You for Your Attention

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