Hierarchical regulation of ecosystem function: material export from urban catchments

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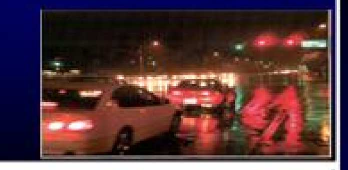

Drops land on, perhaps, a forest, a farm, or an urban industrial sector. After striking down, rain drops coalesce, flow downhill, and gather up a host of materials that accumulated on the land since the previous storm. These materials might include vital nutrients, elevated levels of fertilizer, and metal residue from industrial and commercial enterprises. Storm runoff sweeps these materials into lakes, streams, groundwater aquifers, coastal bays, and landscapes at lower elevations.

Runoff and its associated materials, which ecosystem ecologists often refer to as "load," can pollute these downflow recipient ecosystems. Understanding the processes that generate load is a fundamental issue both for basic ecology and for regulating land practices that impair water quality.

Figure 1. Storm runoff flowing down a canalized river channel. This runoff was created when rainwater landed within a common urban drainage basin (also referred to as a "catchment") and then gathered together along its downhill journey.

Taking a hierarchical view (see Figure 2),

WE INVESTIGATE:

1) Whether material load in storm runoff is influenced by storm attributes.
2) Whether relationships between load and storm attributes vary from one catchment to another.
3) Why the relationships between load and storm attributes differ from one catchment to another.

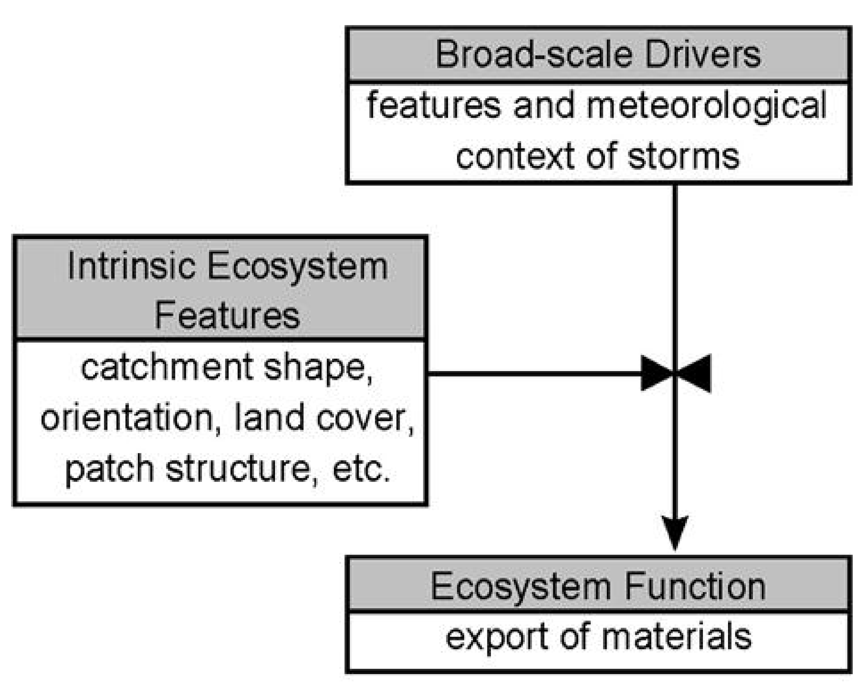

Figure 2. Control of ecosystem function & material load viewed through the lens of Hierarchy Theory. By this theory, intrinsic, fine-scale features of a system can mediate the influence of exogenous, broad-scale forces imposed on that system

WE DEMONSTRATE:

- Export of disparate materials from catchment ecosystems is influenced by attributes of storms (e.g., duration, season, etc.)
- This relationship between material load and storm attributes is shaped by intrinsic features of catchments.
- Previously assumed measures of catchment features – such as the proportion of impervious ground cover – are overly simplistic and insufficient for understanding how storm attributes and catchment features interact to produce load.

How do we estimate load?

Load: total mass of a material (e.g., nitrate or lead) exported from a catchment in storm water runoff.

Load is estimated by analyzing the chemistry of the "stream" of rainwater (e.g., Figure 1) flowing out of a catchment. To study this stream of runoff, a monitoring station is established at the lowest elevation point of each catchment (see Figure 3). Monitoring stations also record attributes of the storms.

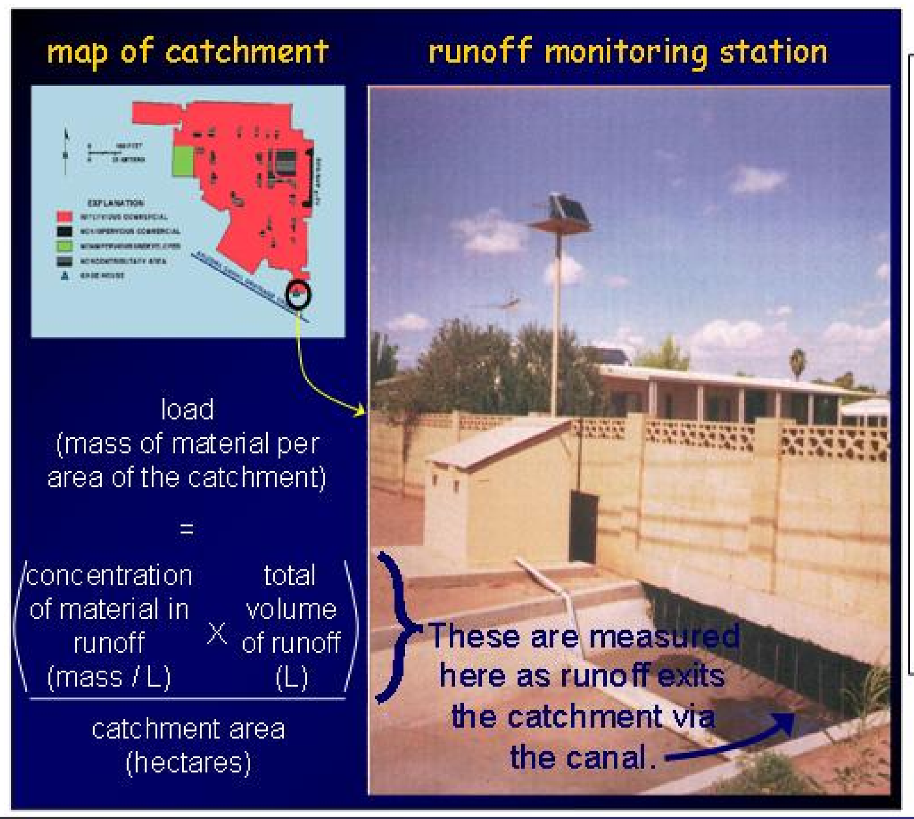

Figure 3. This urban catchment is 1.4 hectares large with impervious cover, & is located at 43rd and Peoria Avenues in Phoenix, Arizona. A monitoring station is located at the catchment's low-elevation point, where the "stream" of storm water runoff flows out of the catchment.

Are the loads of any of these diverse materials…

• Nitrate	• Phosphate	• Chloride	• Copper
• Ammonium	• Total phosphorus	• Water	• Nickel
• Inorganic nitrogen	• Organic carbon	• Arsenic	• Lead
• Organic nitrogen	• Dissolved solids	• Cadmium	• Zinc
• Total nitrogen	• Suspended solids	• Chromium	

…exported from catchments in Figure 4…
…influenced by any of these storm attributes?

- Total precipitation
- Storm intensity
- Storm duration
- Number of storm-free days preceding the storm
- System (Gulf monsoon vs. Pacific frontal) generating the storm

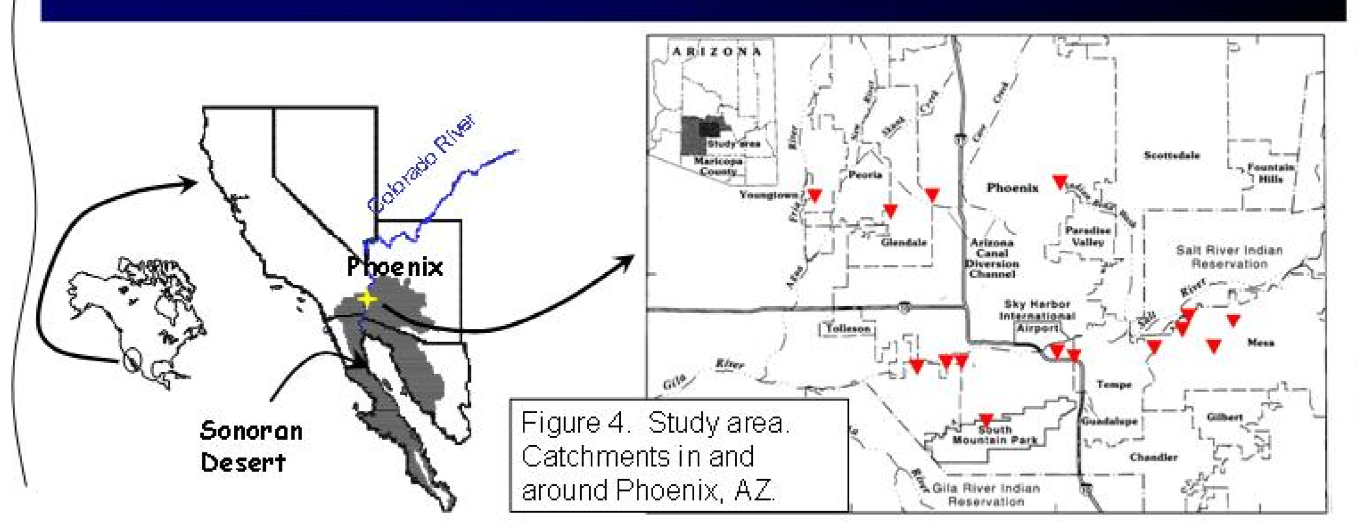

Figure 4. Study area. Catchments in and around Phoenix, AZ

RESULTS

Do storm attributes influence load?	YES
Does the relationship between load and storm attributes differ among catchments?	YES
Does the relationship between load and storm attributes differ among materials?	NO

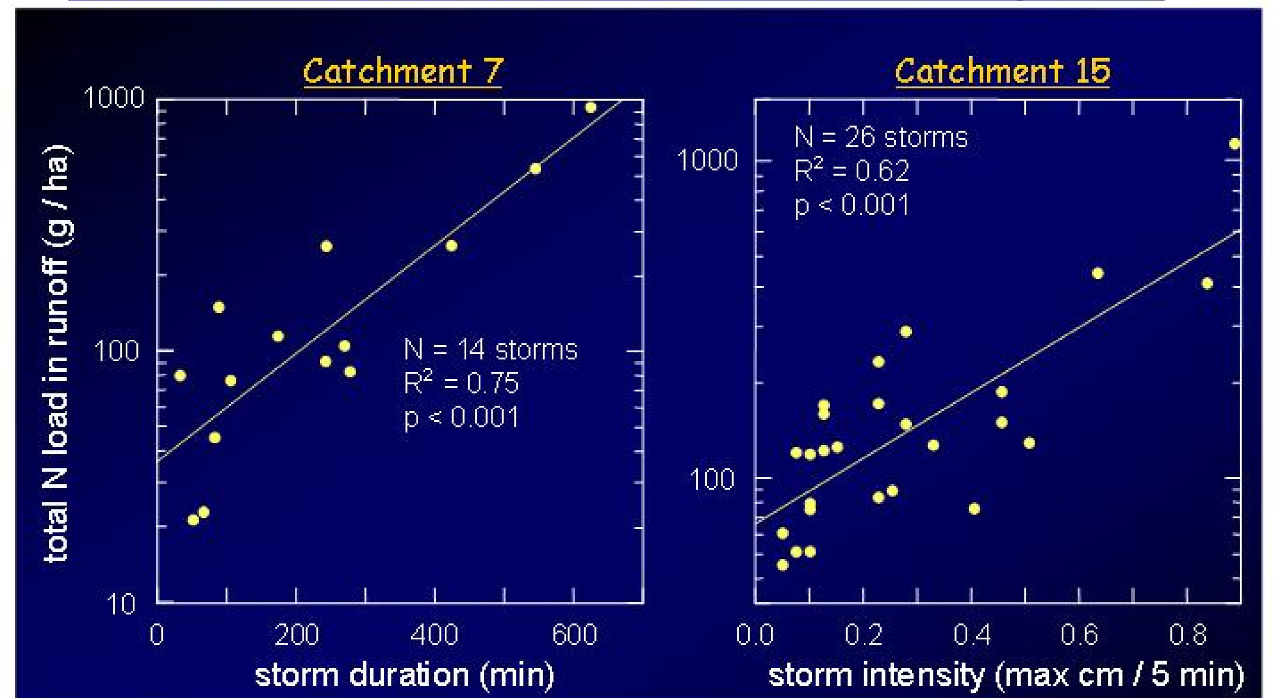

Figure 5. Storm attributes influence the load of total nitrogen exported from catchments in storm runoff. Different storm attributes, however, are related to N load in different catchments.

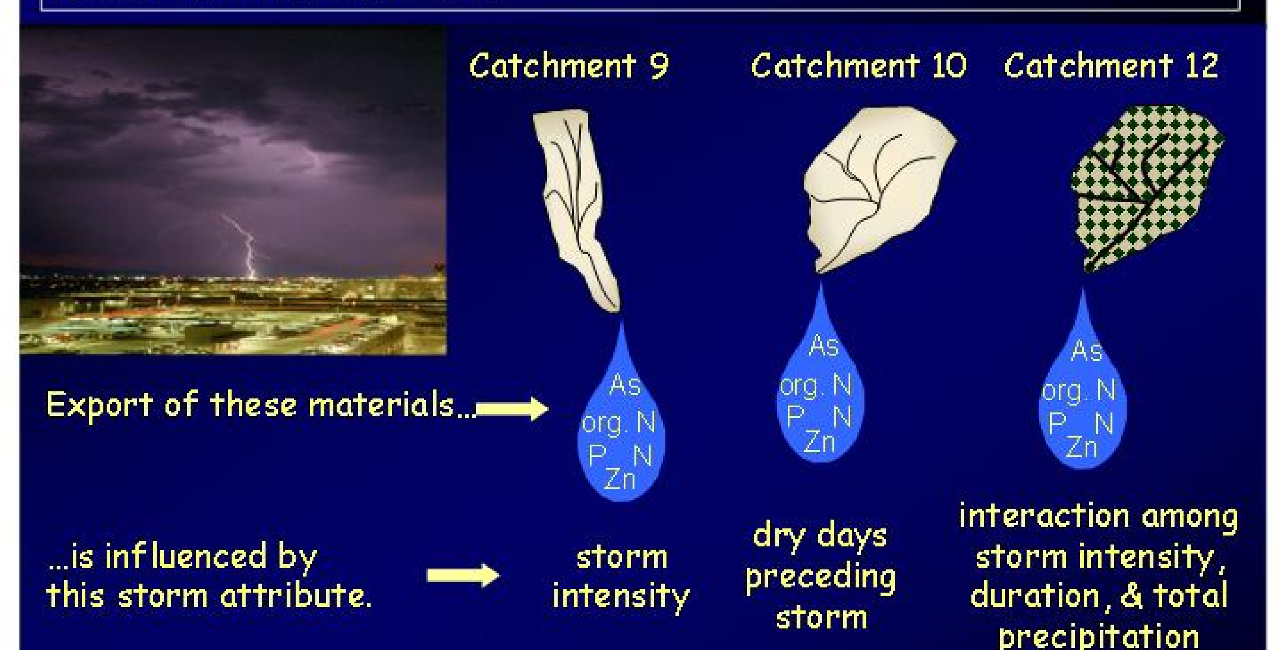

Figure 6. Our models indicate that the loads of many material species are influenced by the same storm attribute for any one catchment. This pattern holds for materials as disparate as nitrogen, the organic fraction of nitrogen, phosphorus, arsenic, and zinc.

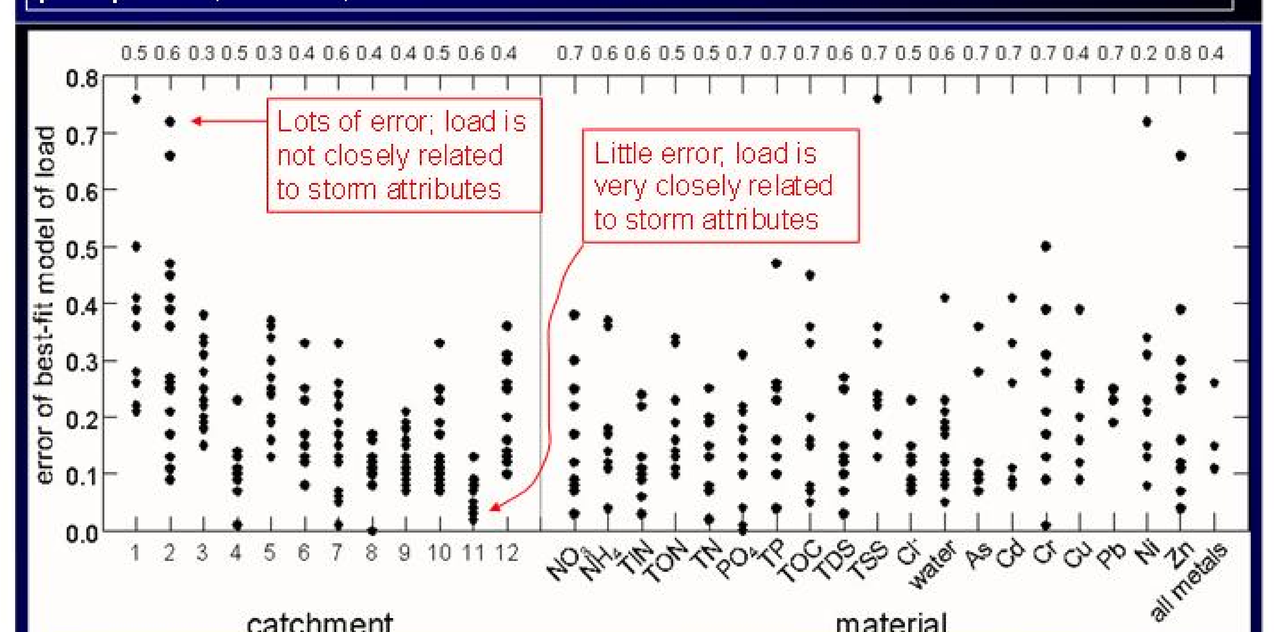

Figure 7. Each point is the error when we use a statistical model to describe the relationship between storm attributes and the load of a particular material from a particular catchment (e.g., load of lead from Catchment #8). When the models are grouped according to the catchment being considered (left panel), one can guess whether the model will have small or large error. When the models are grouped according to the material being considered (right panel), one is less able to guess the amount of error. In other words, the stacks of points in the right panel are generally more spread out than the stacks of points in the left panel (values atop the graph are CVs of the underlying stack of points; CVs to the right are greater than CVs to the left; ANOVA p = 0.009, N = 32).

WE HAVE DEMONSTRATED that features of catchments influence the link between storm attributes & load.

- ❖ What are these features?
- ❖ Are they the simple descriptors typically embraced?
  - ✓ E.g., proportion of land with a certain cover type
- ❖ We argue such simple measures are insufficient to explain:
  - ✓ variability in load (Figure 8)
  - ✓ variability in our capacity to link load to storm attributes

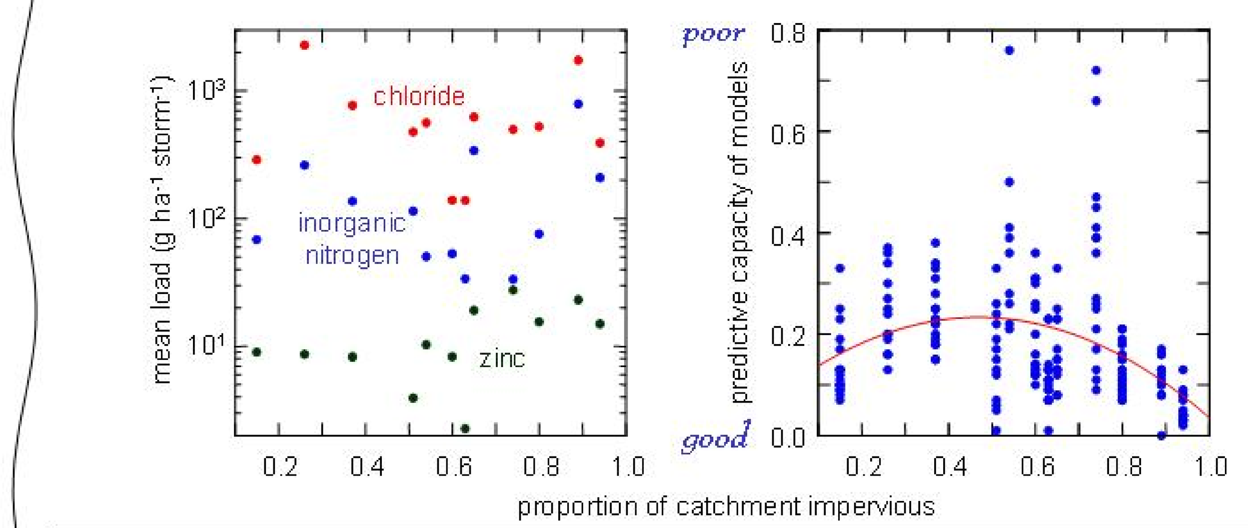

Figure 8. (Left) Mean (across all storm events) load of three different material species exported from a catchment plotted against proportion of impervious cover in the catchment. (Right) Y-axis value is the mean-square error in regression models that fit load as a function of storm attributes; each point is one such model fit to the load of a single material exported from a single catchment. X-axis value is the proportion of impervious cover in the catchments from which load was measured. Red line depicts a 2nd-order polynomial (both terms $p < 0.001$).

Why are these simple measures insufficient, i.e., why are the data in Figure 8 so variable?

HYPOTHESIS: they do not account for ***spatial*** dynamics in the interaction among ***multiple*** catchment features.

For example, "proportion of catchment with impervious cover" may be insufficient because it matters where that impervious cover is located relative to the water conveyance routes that dissect the catchment, and where those routes, in turn, are located relative to sources and sinks of material. Figure 9 conceptualizes this hypothesis.

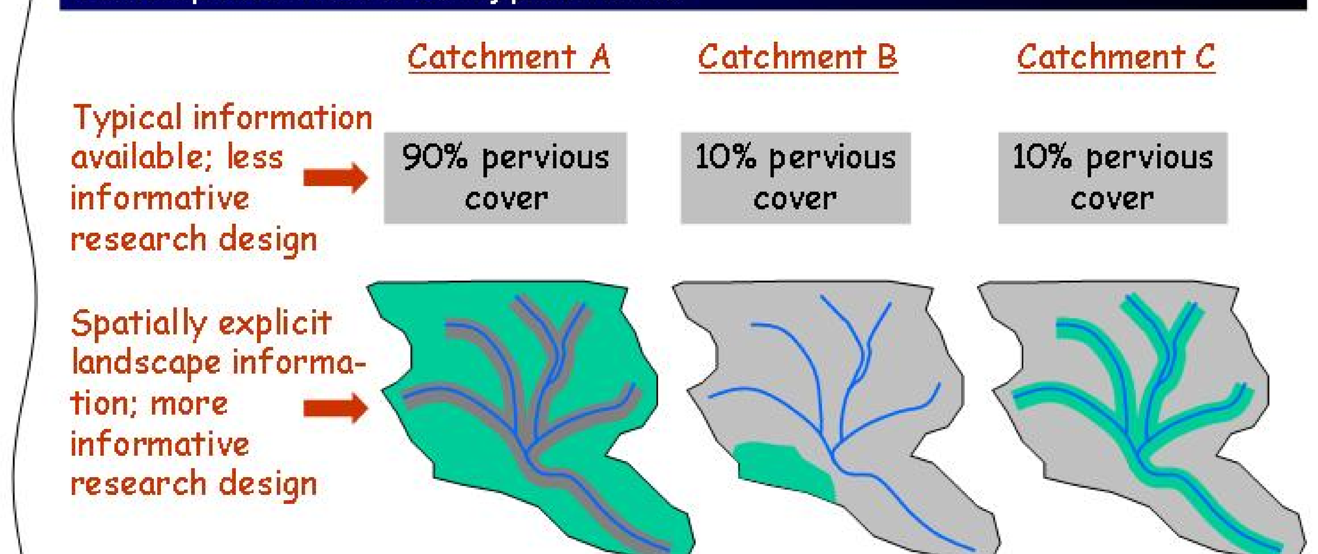

Figure 9. Contrasting simplifications of catchments present very different amounts of information useful in formulating knowledge-generating research designs.