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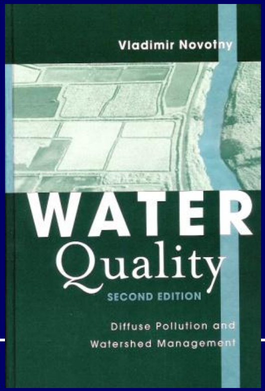
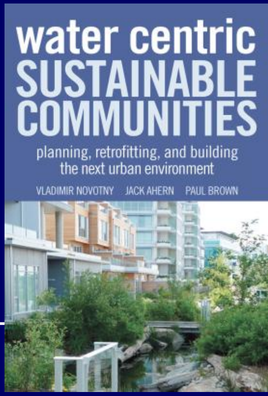
# STREAM RESTORATION

Novotny (2003) WATER QUALITY: Diffuse Pollution and Watershed Management, J. Wiley  Chapter 14
Novotny at al (2010) Water Centric Sustainable Communities, J. Wiley, Chapter 9

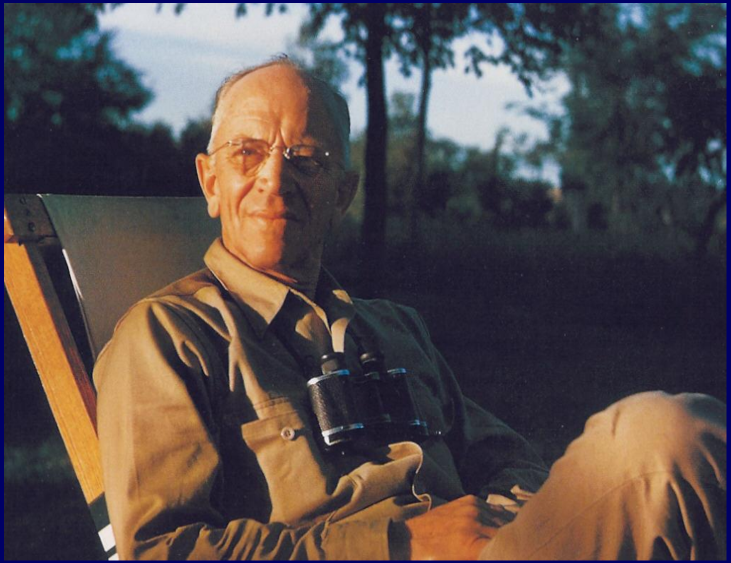




# A water body and its watershed are inseparable

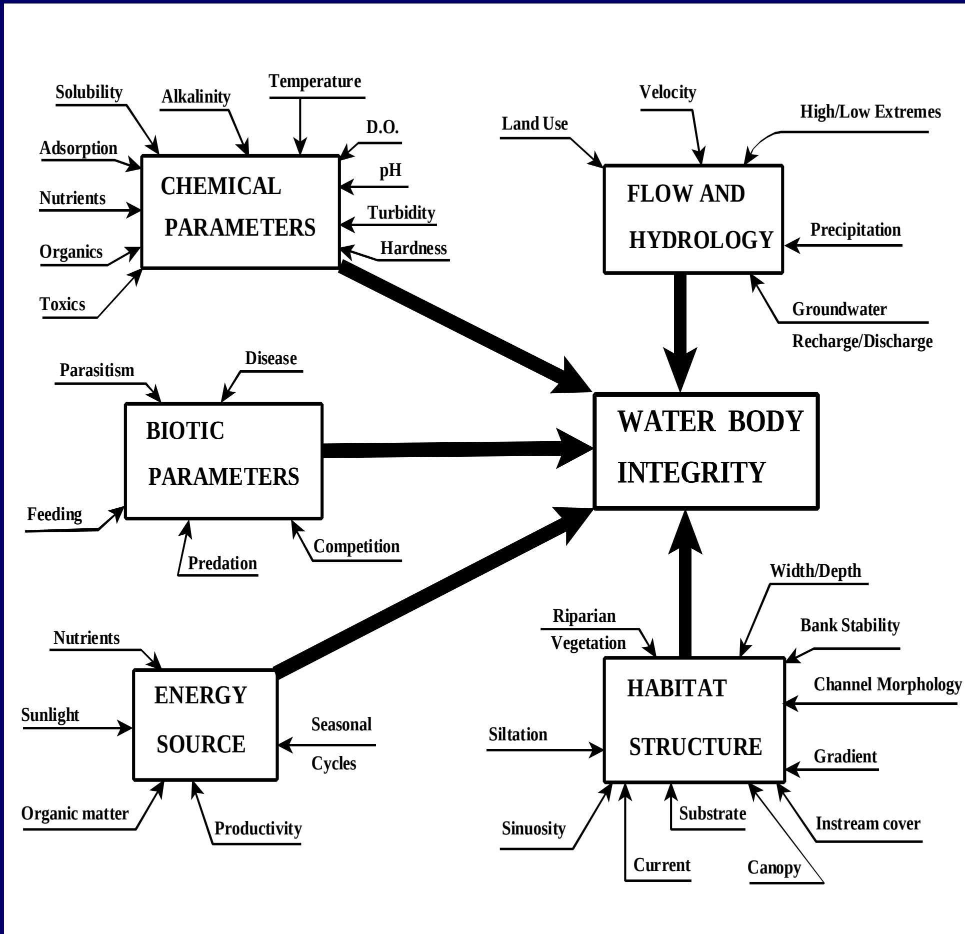
- *The land ethic simply enlarges the boundaries of the community to include soils, waters, plants, and animals, or collectively: the land*.
- To restore a quality of a water body one has to clean – up the watershed first



Aldo Leopold (1887-1949), Professor of Land Conservation, University of Wisconsin

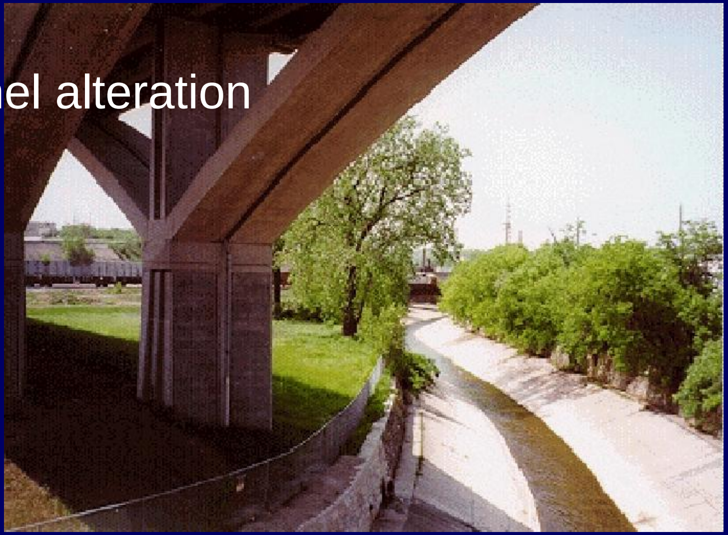
# ECOLOGIC POTENTIAL WATERBODY INTEGRITY

- Maintaining and improving water body integrity is the goal in USA and EU
- Dimensions of integrity
  - Habitat (physical)
  - Chemical
  - Biological
- Integrity: “A balanced, adaptive community of organisms having a species composition and diversity comparable to that of natural biota of the region”



# Definition of Pollution (Clean Water Act)

Channel alteration



- Anything that downgrades the integrity of the water body and is caused by humans or human activities

Urban point and diffuse discharges into Milwaukee Outer Harbor in early 1980s

# Anthropogenic Pollution but not Pollutants

- **Urbanization Effects**
  - **Imperviousness**
    - Increases peak flow
    - Channel lining and cutting trees along the water body
    - Constricting channel by dikes and levees
    - Increases bank erosion
    - Decreases base flow
    - Decreases water quality
  - **Substrate degrada**tion
    - Embeddedness
    - Habitat loss and fragmentation
    - Contaminated sediment (legacy pollution)

- **Water use and wastewater disposal**
  - Flow diversions and withdrawals
  - Effluent dominated sections
- **Ecological longitudinal fragmentation (interruption of fish and biota migration)**
  - Bridges and culverts (often impassable for aquatic biota)
  - Drop structures to reduce velocity
  - Dams
  - Concrete lining of channel creating shallow often supercritical flow
- **Narrowing or loss of riparian ecological systems**
  - Floodplain development
  - Riparian wetland drainage

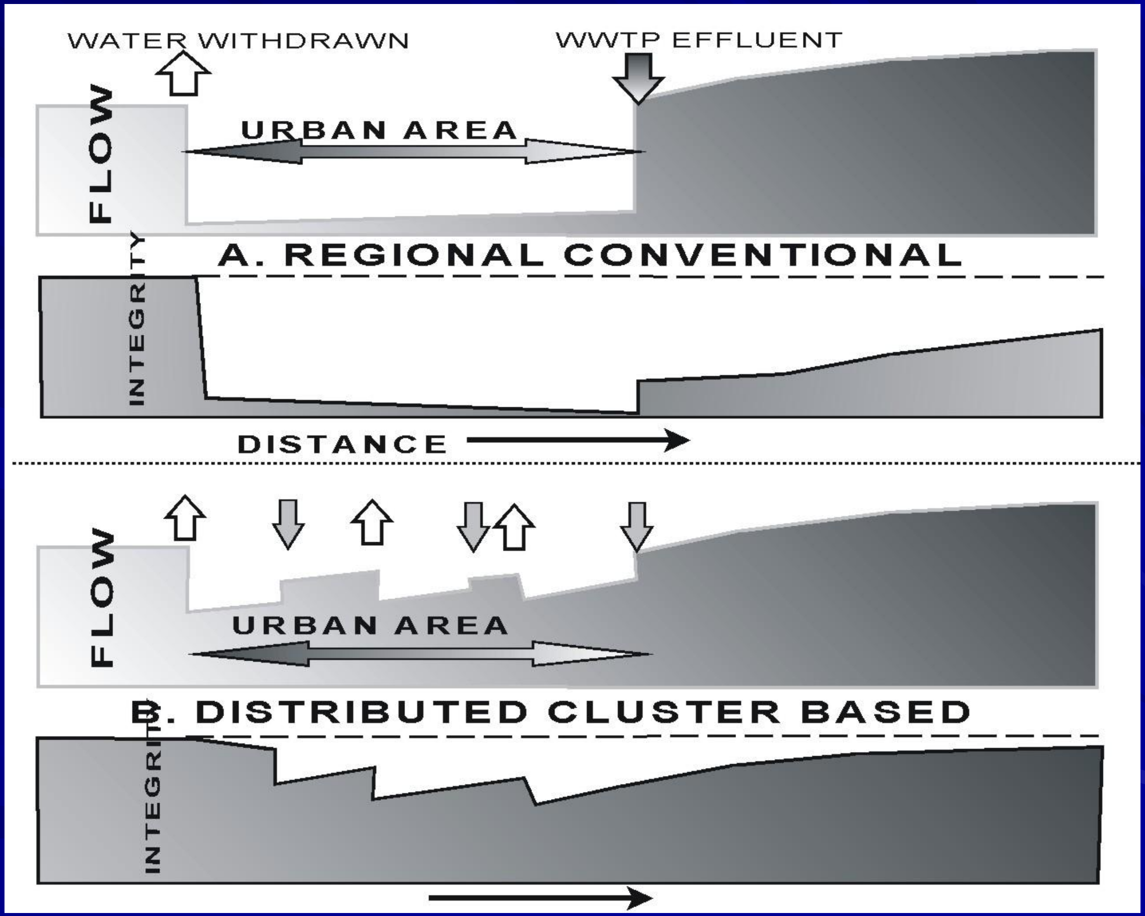
# Examples of longitudinal fragmentation

Impassable culvert

Drop structure

# Flow deprived and effluent dominated urban streams

Gila River upstream and
downstream of Phoenix (AZ) WWTP
(photo R. Meyerhoff, CDM)



# Nature Response

- Flooding
- Channel erosion
- Channel enlargement
- Accumulation of sediments behind dams and in harbors
- Floodplain enlargement

# Stream bank erosion

Fish Creek

in Mequon, WI

Leopold, Wolman & Miller, 1994

Urbanizations makes flows more flashy therefore channels become unstable and eroding until a new equilibrium is reached. In the same time base flow is diminishing.

Natural streams are in an "equilibrium" with the flows when the bank capacity flow is about 1.5 to 2.5 years recurrence high flow.

# Problems

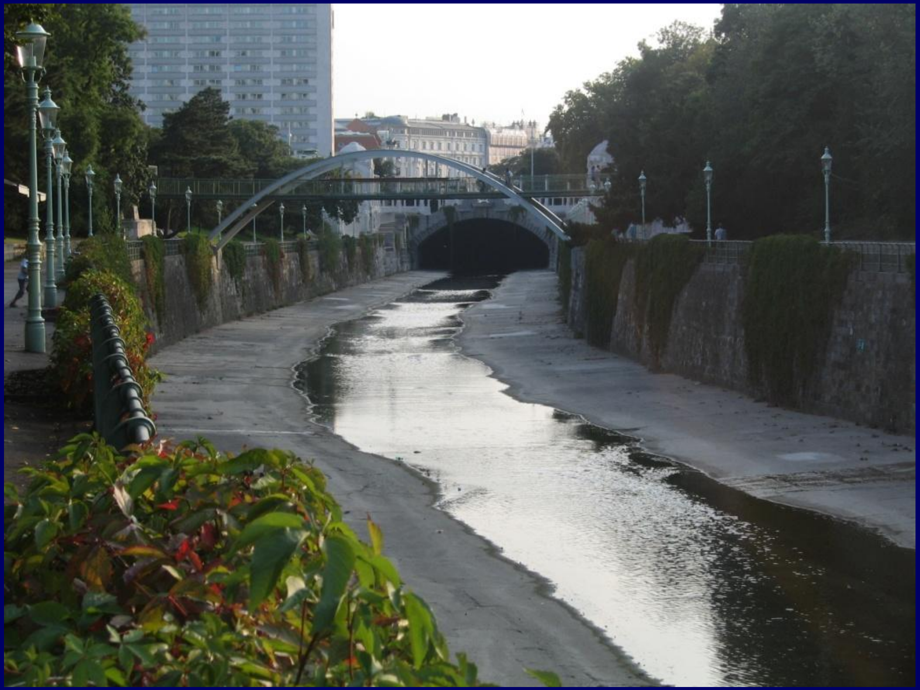
- **Drinking water taste, odor problems, contamination by organic pollutants**
- **Excessive developments of algae (e.g., Cladophora) or cyanobacteria (blue-greens)**
- **Low dissolved oxygen levels, fish kills**
- **Poor fishing, loss of higher quality less tolerant species, loss of biotic integrity**
- **Sedimentation and siltation of habitat**
- **Loss of recreation and aesthetics**

# Overuse

Los Angeles River

- Too much water withdrawn from the river and groundwater for water supply
- Flood control by fast conveyance
- Habitat destruction
- Lifeless river unfit for statutory uses of aquatic life and recreation

# Lifeless canal in Vienna, Austria



This canal used to be  a part of the defense of the city.

# Goals of water body restoration

- Restoration
  - Return to the predevelopment natural status
- Rehabilitation
  - Finding the optimum ecological potential
- Components
  - Control point and nonpoint sources
  - Provide habitat and conditions for fish and other organisms
  - Control erosion
  - Provide recreation
  - Control flooding

# SOLUTIONS

## Watershed/Stream Corridor Restoration

- Mitigate as best as possible the cause of the disturbance and damage first
  - BMPs for diffuse pollution and point source controls by treatment
  - Implement storage and BMPs for stormwater and CSO controls
- Restore floodplain and reconnect stream to its floodplain
  - Reduces flashiness and flooding
- Restore/recreate riparian wetlands
  - Improves water quality and wildlife habitat
  - Improves hydrology of the stream
- Restore/create instream habitat
  - Improves fish and invertebrate population
  - Remove or reduce longitudinal fragmentation
- Provide adequate base flow
  - Provides dilution and conditions for aquatic biota survival
- Provide opportunities for recreation and enjoyment of citizens

# Is a beautifully landscaped urban river always sustainable?

SAN ANTONIO RIVER , TEXAS

# Is a beautifully landscaped urban river always sustainable?

**PROBLEMS S.A. River is an impounded basin suffering from**

- **Anoxia**
- **Poor or no habitat**
- **High turbidity**
- **High nutrient content**
- **Poor aquatic life**

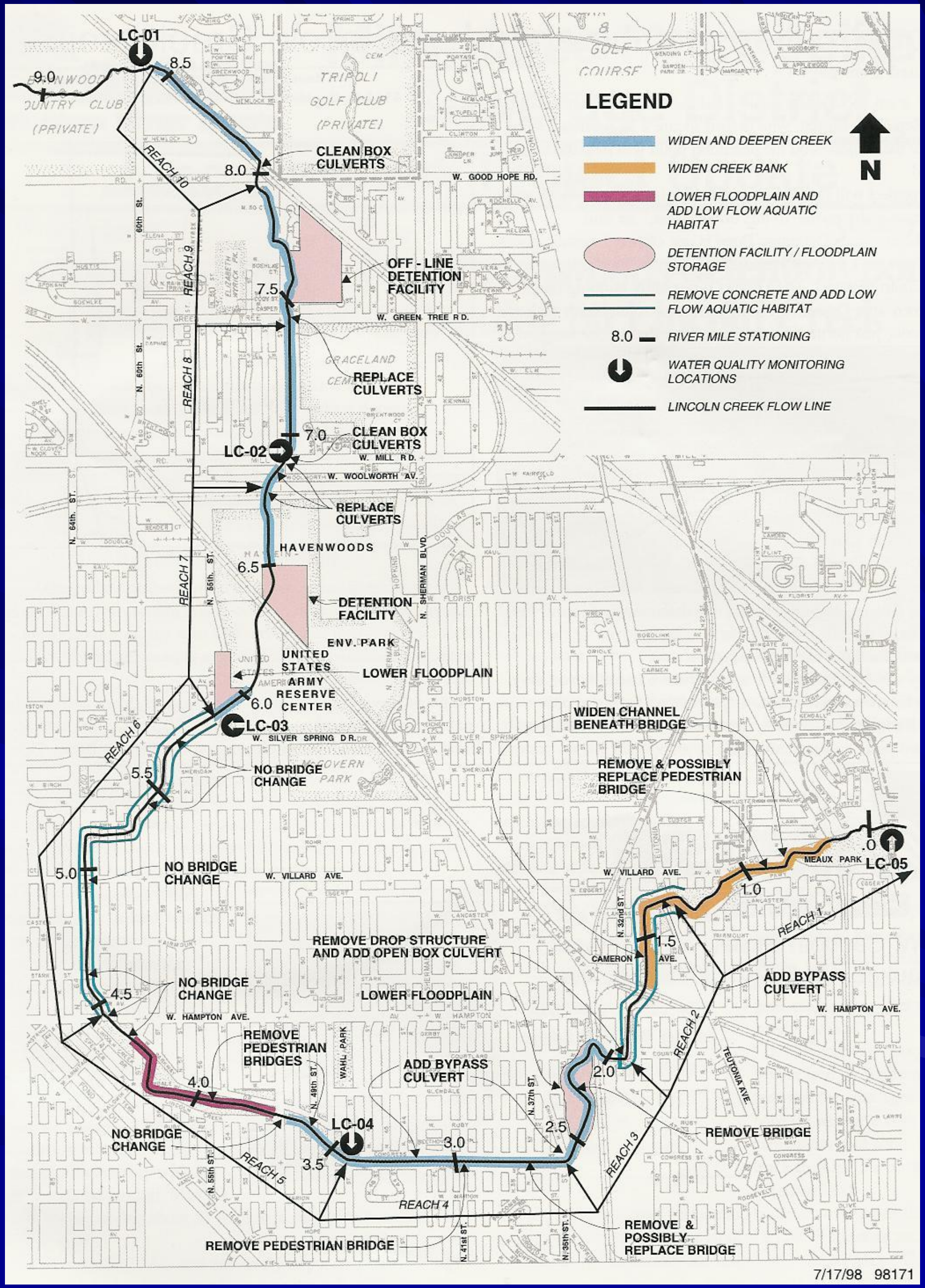
SAN ANTONIO RIVER , TEXAS

# Lincoln Creek

# Milwaukee

**An urban stream affected by flooding and impaired by storm and combined sewer discharges**

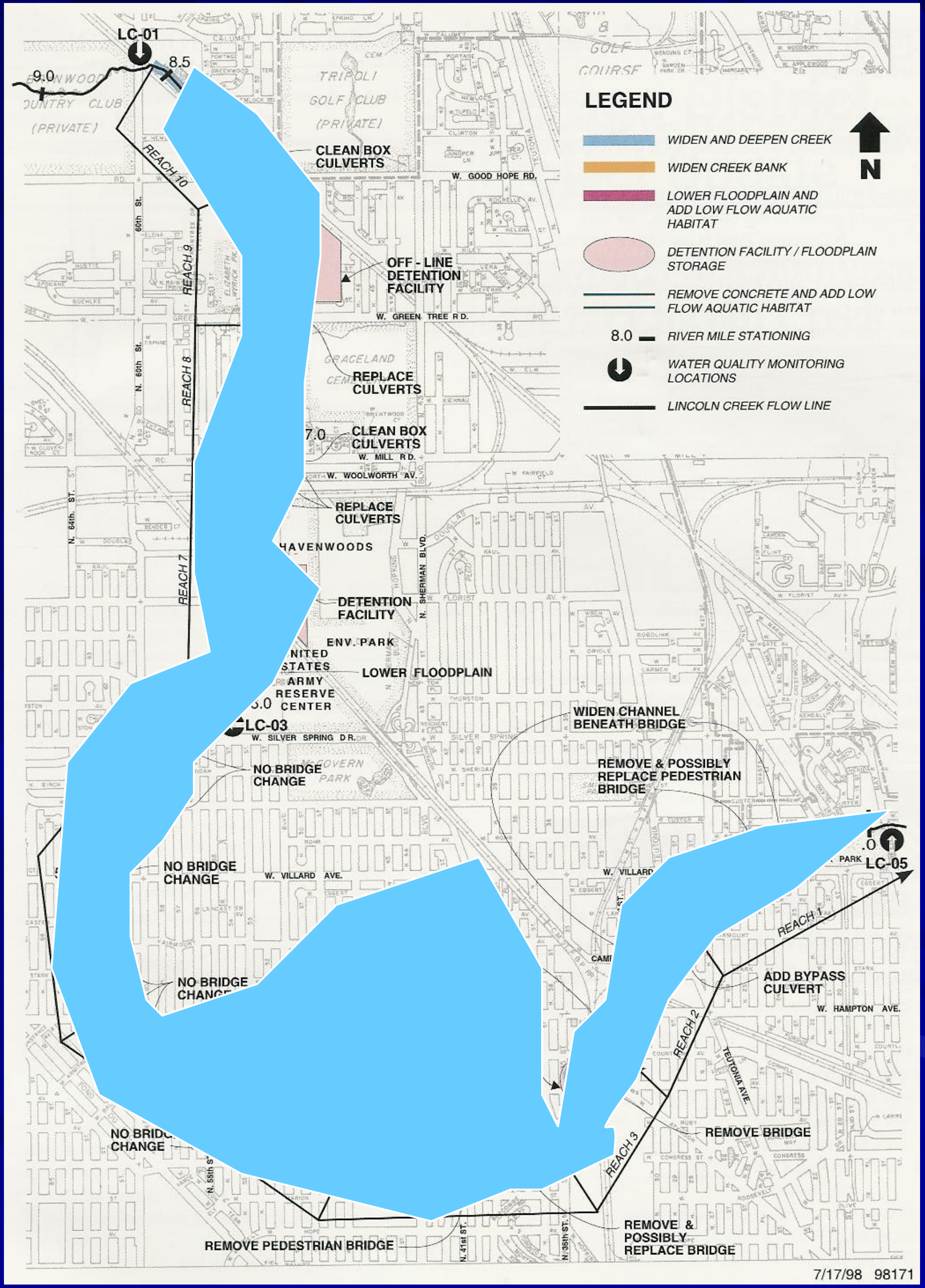
1600 homes affected by flooding



# Lincoln Creek

# Milwaukee

**An urban stream affected by flooding and impaired by storm and combined sewer discharges**



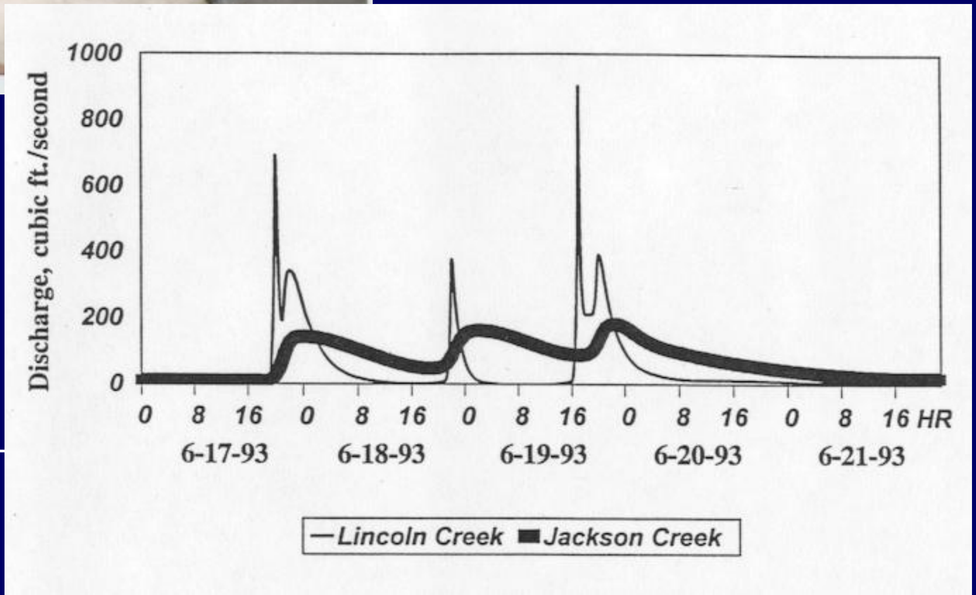

1600 homes affected by flooding

# Solution?
# Fast conveyance ? Or not?

Channelization as well as combined sewer overflows are pollution because they impair development and propagation of a balanced aquatic biota.

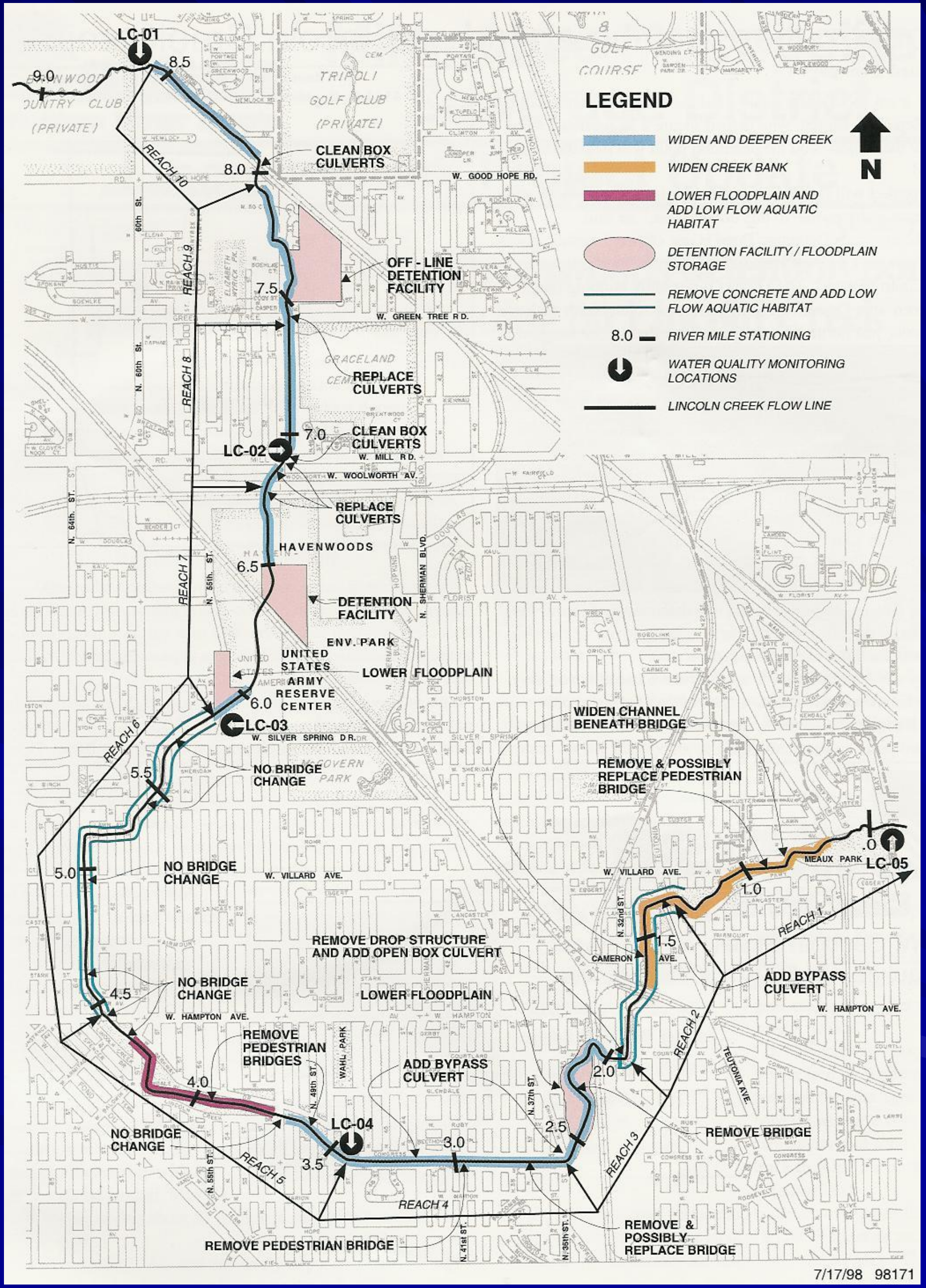
"Old" Lincoln Creek

**Impact of fast conveyance**

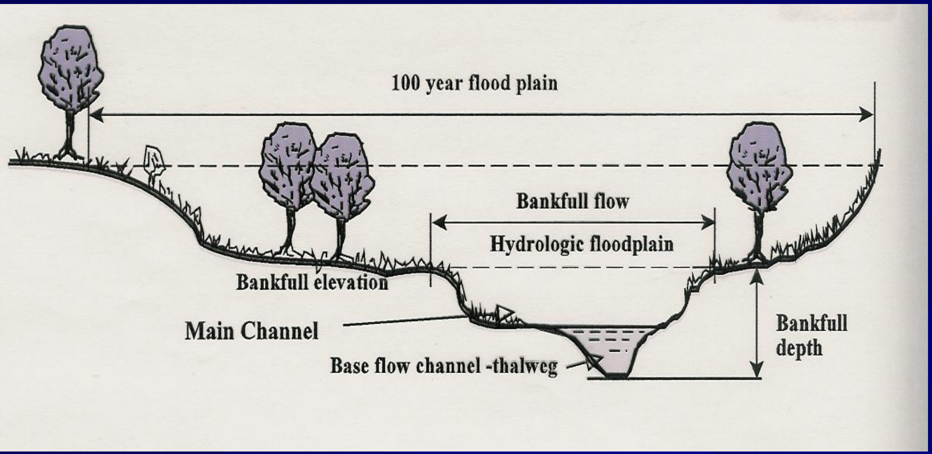


# Solution to restore the creek and provide also flood protection

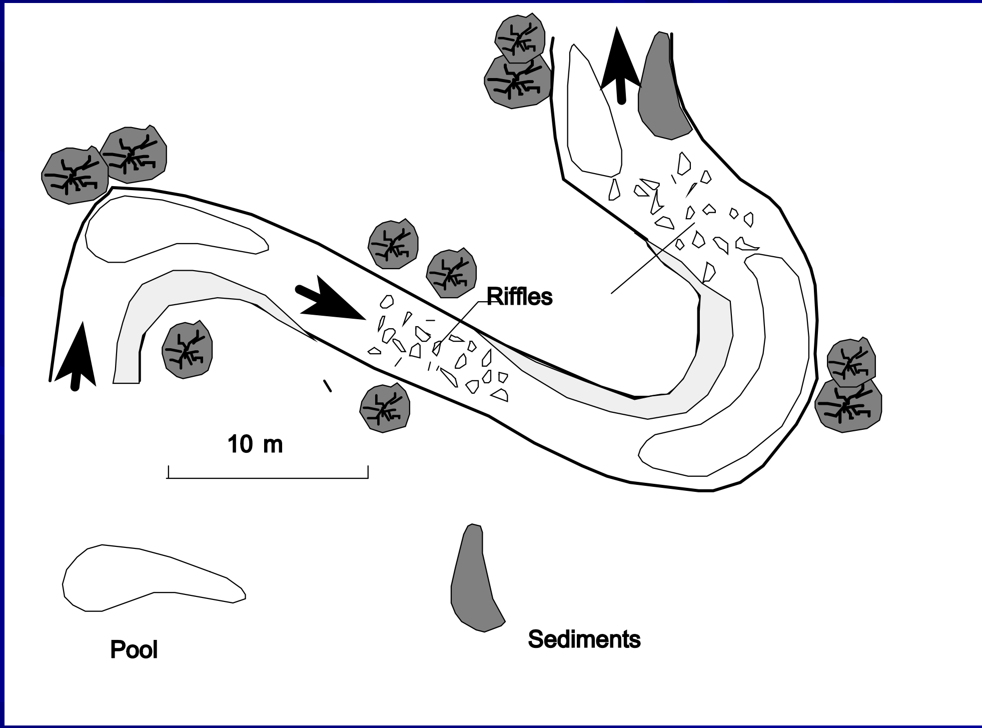
- Remove concrete from the channel and restore habitat
- Control CSOs
- Provide storage
- Create wetlands
- Remove bottlenecks



# Natural Channel




Cross-section



# STREAM CREATION/RESTORATION

## Natural Systems and their BMP equivalents

| Natural systems | Nature mimicking Best Management Practices |
|---|---|
| Watershed with infiltration | Pervious pavements, green roofs with French well or rain garden infiltration of downspout excess water |
| Ephemeral pre-stream channels | Rain gardens, buffers sand filters connected to landscaped swales or dry storage ponds for flood water |
| 1st order perennial streams with base water flow from<br>○ Springs<br>○ Headwater Wetlands<br>○ Headwater lakes | Daylighted, restored or created streams with base flow from<br>○ Groundwater infiltration, including dewatering basements<br>○ Decentralized high efficiency treatment plant effluents<br>○ Restored or created wetlands<br>○ Wet ponds with stored storm water |
| 2nd order streams | Restored original streams with reclaimed floodplains and riparian wetlands; floodplain converted to recreational park and buffer zones; storage in lakes and ponds in the reclaimed flood plains |
| 3rd and higher order streams | Removal of channelization and impoundments wherever possible, providing flood storage. Significant portion of flow may originate from upstream nonurbanizaed areas. |

# Restoration of Lincoln Creek

Upper (above) and lower (right) restored Lincoln Creek

New habitat in the channel

Photos by the author

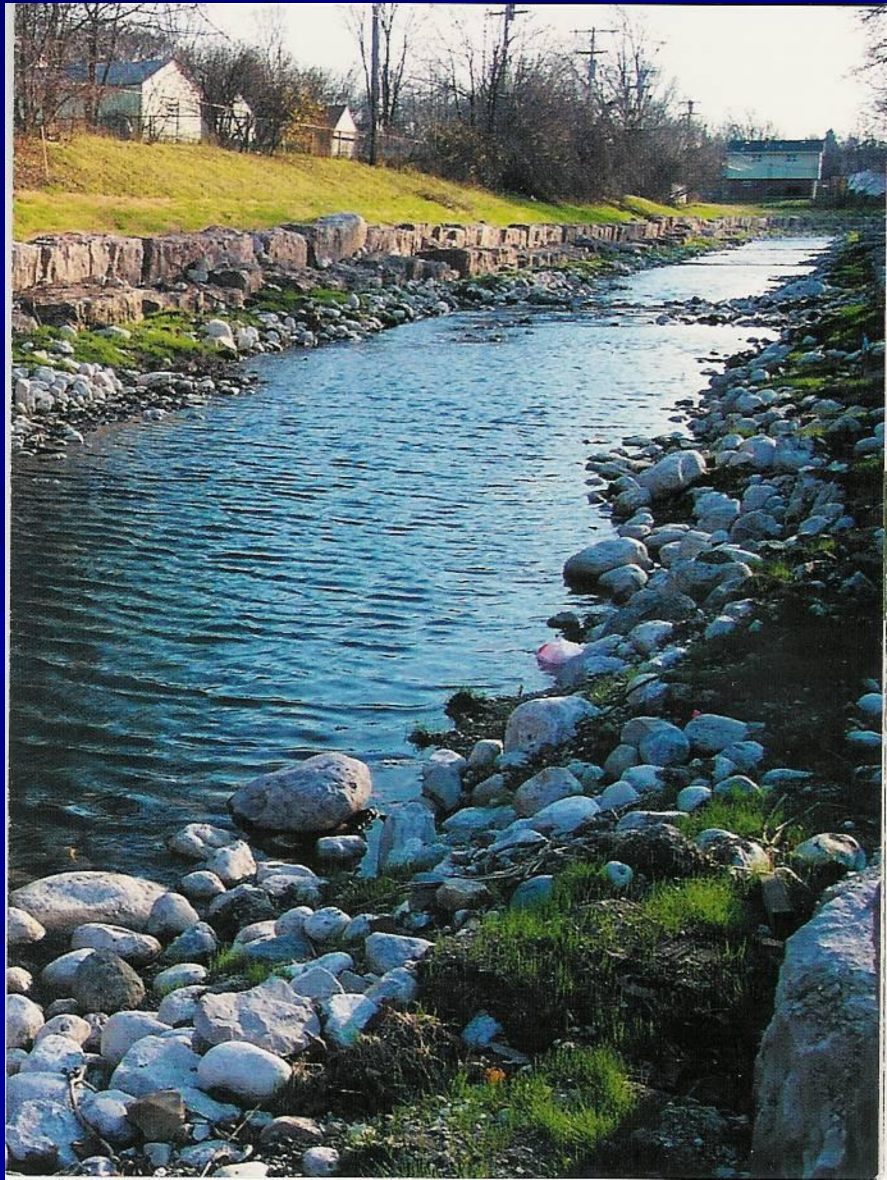

Reclaimed floodplain, created wetland and floodplain storage

Lower part of Lincoln Creek

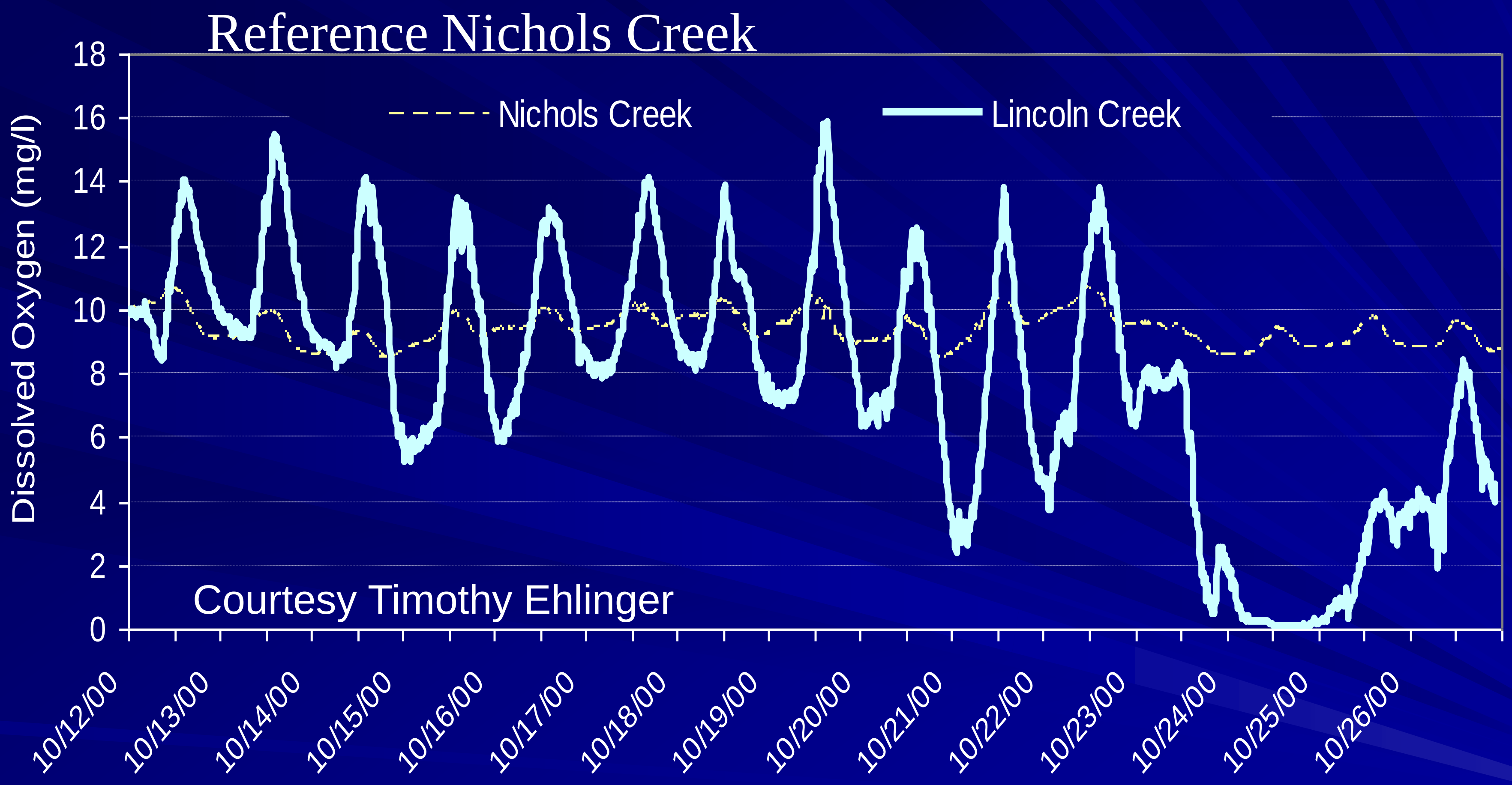
Photo V. Novotny

# Benefits of restoration

- Flow capacity and storage was increased and 1600 homes were removed from the floodplain
- Habitat was fully restored
- Water quality has improved and fish has returned
- Eroding banks were stabilized
- The creek has become an attractive focus of the community



# PROBLEM?




**Water quality of untreated urban runoff cannot support a balanced aquatic community. DO problem is caused by excessive growths of *Cladophora* caused by nutrient content**

# Wetland Restoration

In many states and countries, wetlands are being restored.

Wetlands remove more than 90 percent of suspended solids, BOD and nitrate nitrogen. They are less effective for removing ammonium and phosphates. In colder climates, wetlands are dormant during winter and are inefficient for removing pollutants. Metals and some organic chemicals are effectively immobilized due to reducing conditions in the substrate that also denitrify nitrates.

Created wetland construction in Florida

RIPARIAN WETLANDS ALSO PROVIDE STORAGE IN THE FLOOODPLAIN AND IMPROVE BASE FLOW CONDITIONS. THEY ALSO REPAIR ECOLOGICAL DAMAGES BY IMPROVING LATERAL CONNECTIVITY OF THE HABITAT.

Restored riparian wetland in Iowa

# IMPACT OF WETLAND DRAINAGE

Ca'di Mezzo recreated wetland – Venice Lagoon

- Nitrification of stored organic nitrogen and release of nitrate
- Release of metals stored as metal sulfides
- Loss of pollutant retention capacity "Wetlands are kidneys of nature"
  - BOD and SS removal > 90%
  - Significant removals (immobilization) of toxics
  - pH control
  - High nitrate removal
- Wetlands are naturally dystrophic (low pH and dissolved oxygen)

WETLANDS AROUND THE LAGOON OF VENICE (IT) ARE BEING RESTORED

# RIPARIAN BUFFER STRIPS


THE DESIGN OF BUFFER STRIPS IS MORE AN ART THAN SCIENCE.  THERE IS A NEED TO DEVELOP  MODELS AND METHODOLOGIES

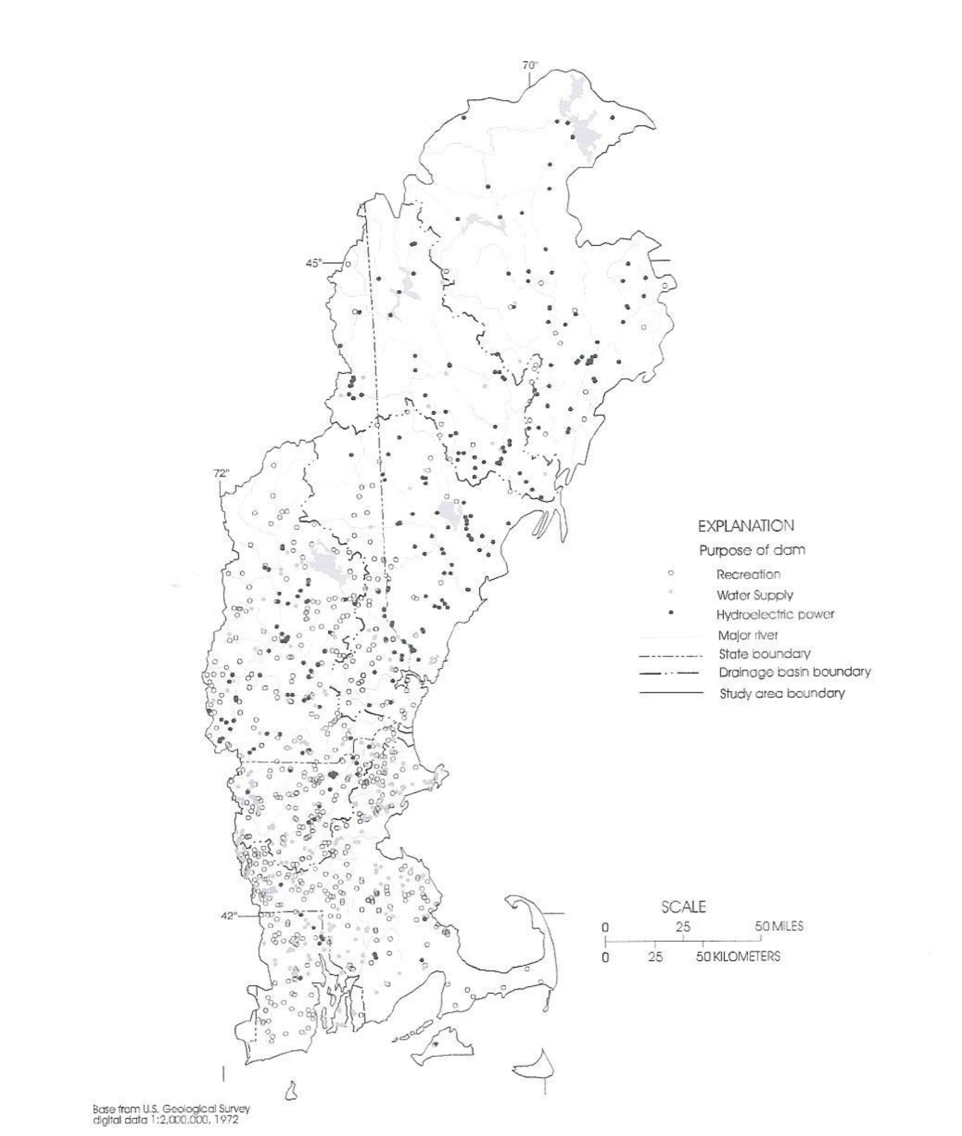
Bear Creek in Iowa

In the Food Security Act the US Congress authorized the Conservation Reserve Program that pays farmers for set aside lands on high slope erosive lands and along the receiving water bodies (riparian buffer strips).

Research docummented that when the riparian buffer strips are properly designed they dramatically reduce concentrations of sediment, nutrients and pesticides in runoff and subsurface flow.

Flood plain storage

# Unused dams removal




Many dams built more than hundred years ago to provide energy for mills, small navigation and power have lost their utility. Today, they are water quality impediments , cause longitudinal fragmentation by preventing migration and are a source of legacy pollution in contaminated sediments.

Riverine dams in New England

# Milwaukee River Restoration


## Stages of the restoration project:

1. Impoundment drawn down in 1990 for repairs. Concurrent studies about feasibility of removing the dam and water quality benefits.
2. Mudflats revegetated and studies concluded 1991-1993.
3. Dam removed 1996-1998, sediments capped and revegetated, banks stabilized.
4. Fish returned 1998 (salmon runs, good quality fishing).

For 100 years the dam had no major beneficial use.

After the Milwaukee Pollution Abatement Plan was completed in 1994, most pollution inputs (CSOs) were diverted to the deep tunnel.

A study of the impact of dam removal was conducted by Marquette University showing the benefits.  The design followed.

# Control of CSOs in Milwaukee

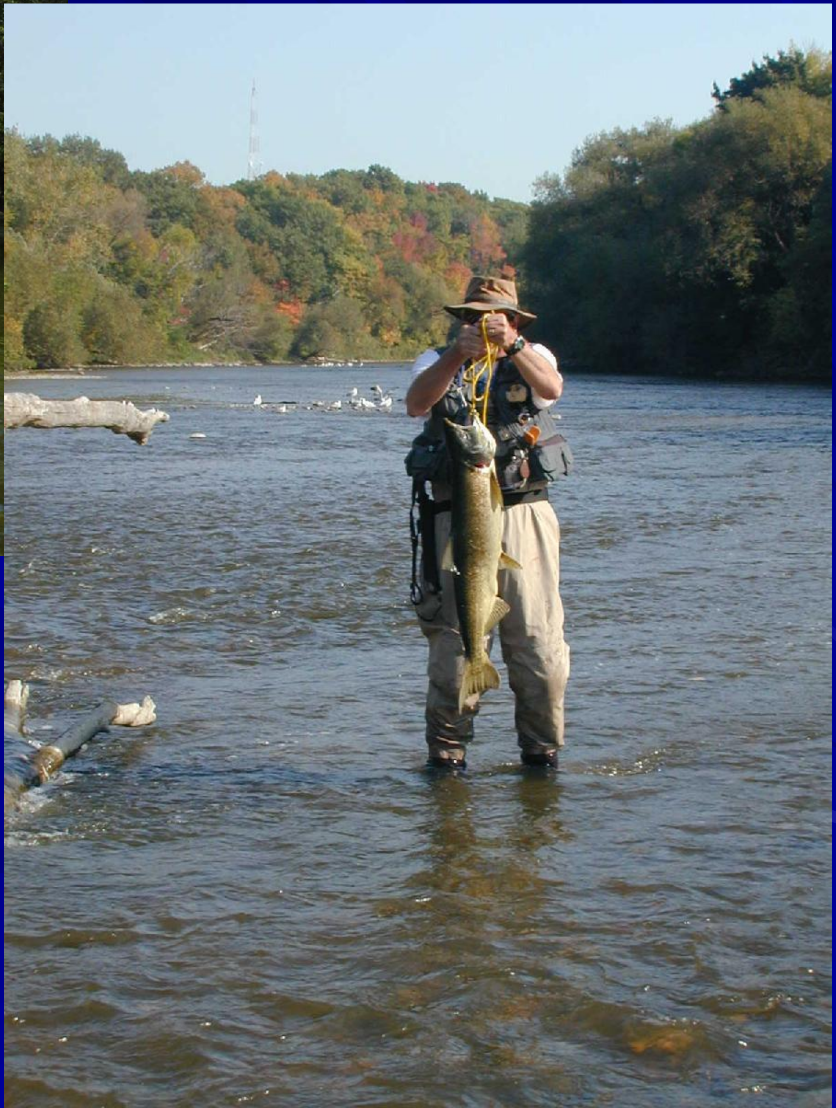
Milwaukee has build 4 million m3 underground tunnel to store CSOs and by-passes from sanitary sewers. The tunnel reduced the frequency of overflows from about 40/year to 2/year. The target frequency was ordered by a court.

The tunnel was drilled 100 meter below surface in the dolomite formation (soft rock). Wall of the tunnel were grouted by epoxy grout to minimize groundwater infiltration.


Before 1990


Restoration - mid 1990s


Drawdown mid 1990s



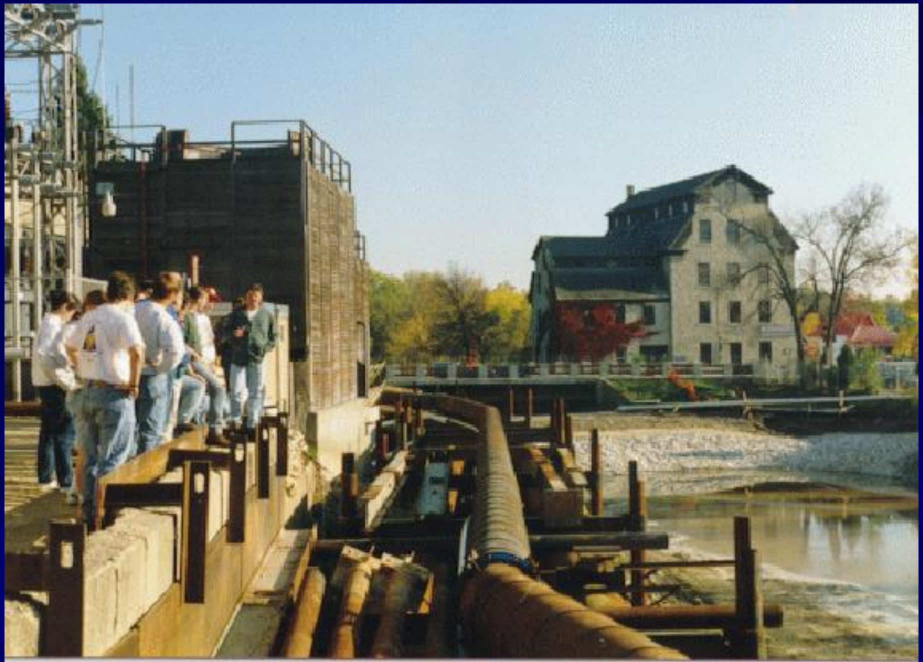
Milwaukee River in 2005

# CEDAR CREEK RESTORATION (Cedarburg, WI)

Cedar creek is the a major tributary of Milwaukee River. Twenty years ago the sediments behind two dams in the City of Cedarburg were heavily contaminated by PCB brought in by runoff from two industrial operations.

The PCB concentrations in the sediments were very high, exceeding in places 10 %. Sediments has to be removed and moved to safe landfills.

The figure shows sediment removal. The entire flow of the creek was by-passed.



# ROCK POND ON CEDAR CREEK

After contaminated sediments were removed clean fill and gravel was put on the bottom.

Cedar Creek after restoration

# Helping the river after Restoration

Side Elevated Pool Aeration – SEPA on Chicago waterways, water is pumped to the upper pool and cascades back while aerating (courtesy MWRD of Greater Chicago)

After restoration or rehabilitation some streams may not be able to attain the goals without a help and must be managed .

1) Artificial aeration during DO emergencies
2) Fish restocking
3) Fish ladders
4) Flow augmentation
5) Trash clean-up

# Let the people and wildlife coexist and enjoy the river

Kamo River in Kyoto (Japan)

The Kamogawa (Wild Duck River) transect the old capital city of Japan from north to south. After clean up and restoration the river hosts a rich ecosystem and is alive with fish and water fowl. Stepping stones provide access for the people to enjoy the river.

Photo V. Novotny

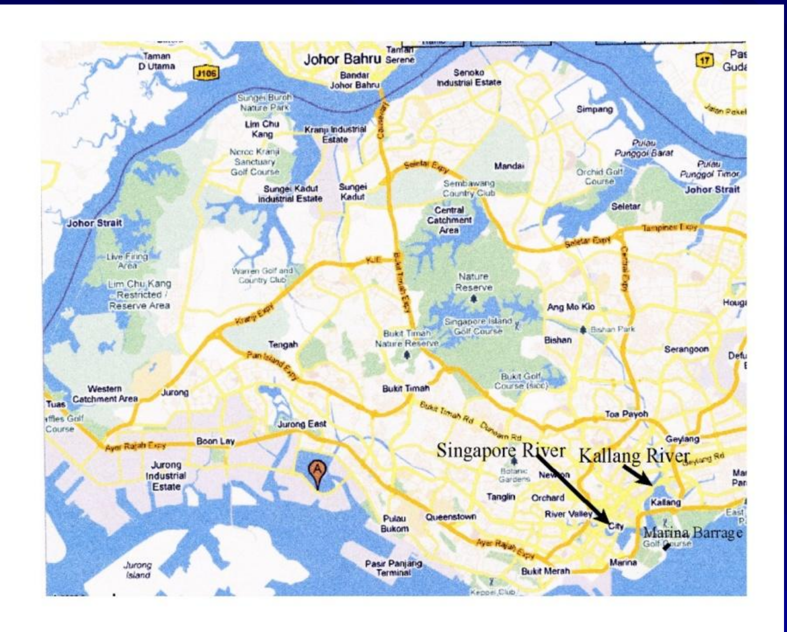
# Provide fish passage and restore habitat

Kamo River in Kyoto

Wetland refuge (above) and fish ladder (right)

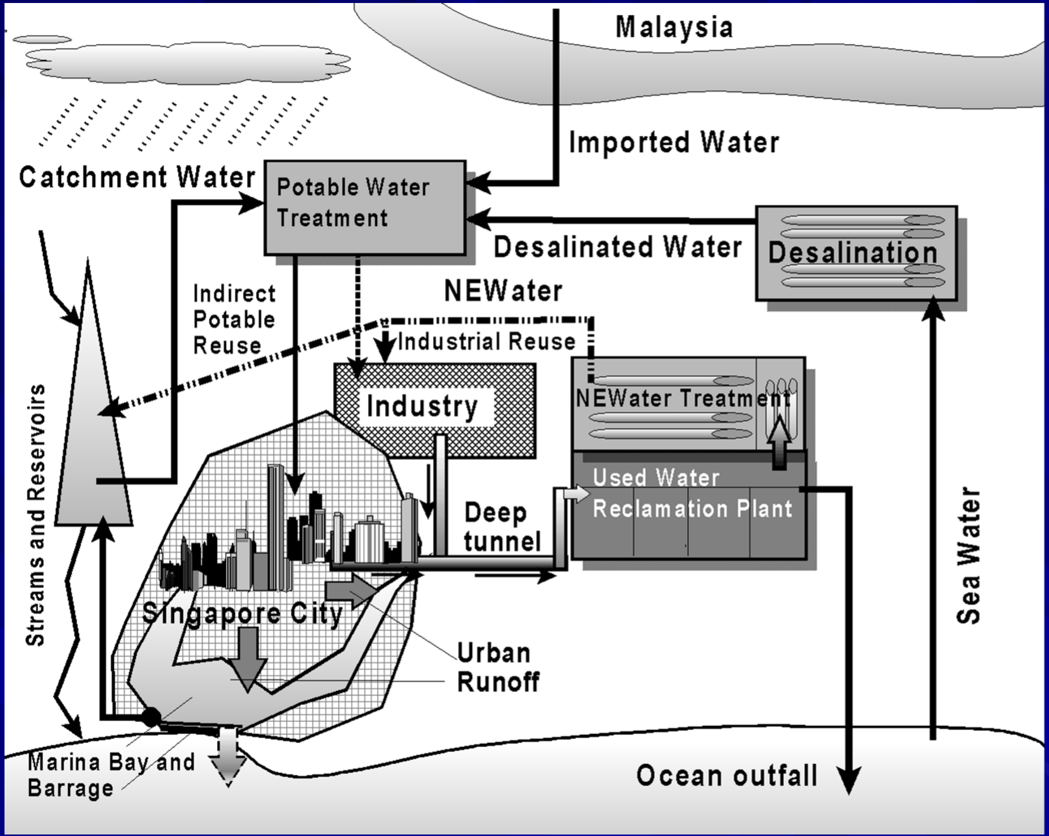
Photo V. Novotny 2010

# Water Quality Management in Singapore




Singapore and Kallang Rivers, Marina Bay

- Before 1980 – Heavily polluted estuary (sewage, pig wastes, heavily polluted urban runoff, oil spills, unsewered premises)
- 1977-1987 A complete clean-up and seweriage, polluting industries and activities removed, street and household refuse collected daily




A small island republic at the equator
Area ~ 710 km$^2$
Population ~ 5 million
One of the highest per capita GNP and living standard in the world
Specific water use 157 L/cap-day

# Marina Barrage and Bay

- 1995 – 2005 Marina Barrage changed the estuary into a fresh water non tidal reservoir from which some water will be reused
- Marina Bay  is a tourist attraction and center of the republic

Photos by v. Novotny

# Kallang River in Singapore

## Bishan Park

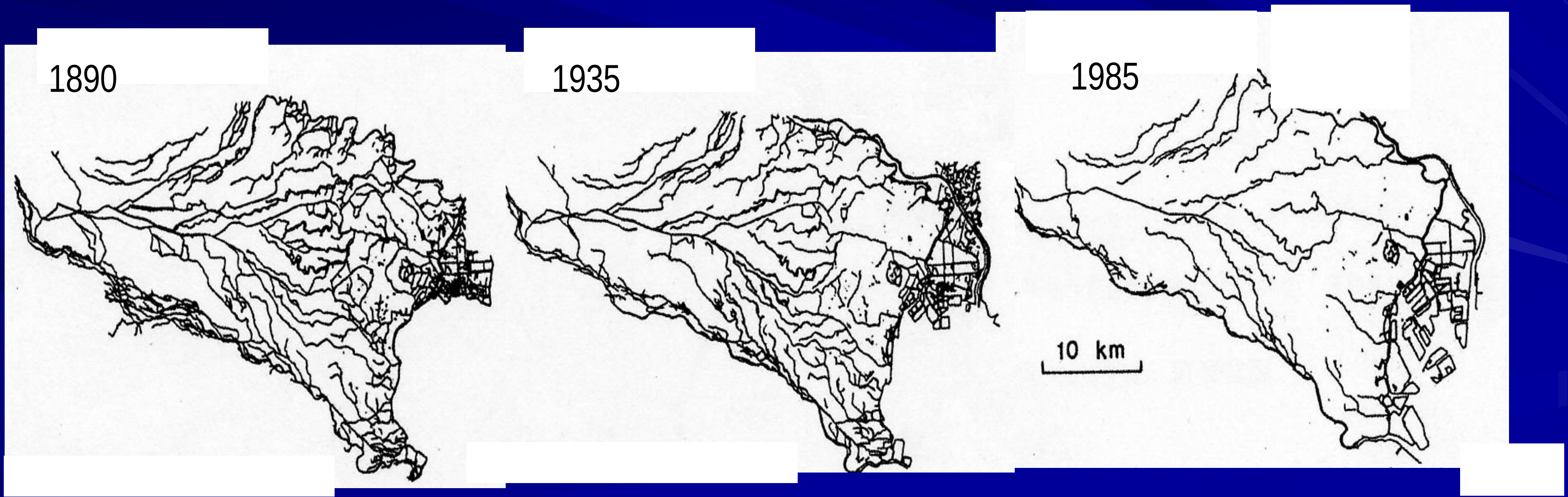
2010 CDM photo (left)
Future restoration (artist rendition provided by PUB, Singapore )

Restoration and water quality management of the Kallang River includes:

- Extensive application of BMPs for stormwater quality controls throughout the watershed
- Renaturalization of the river and its corridor with biotopes for enhanced clean up and ecology
- Improved park and nature setting and access to the river for recreation and wading

# DAYLIGTHING

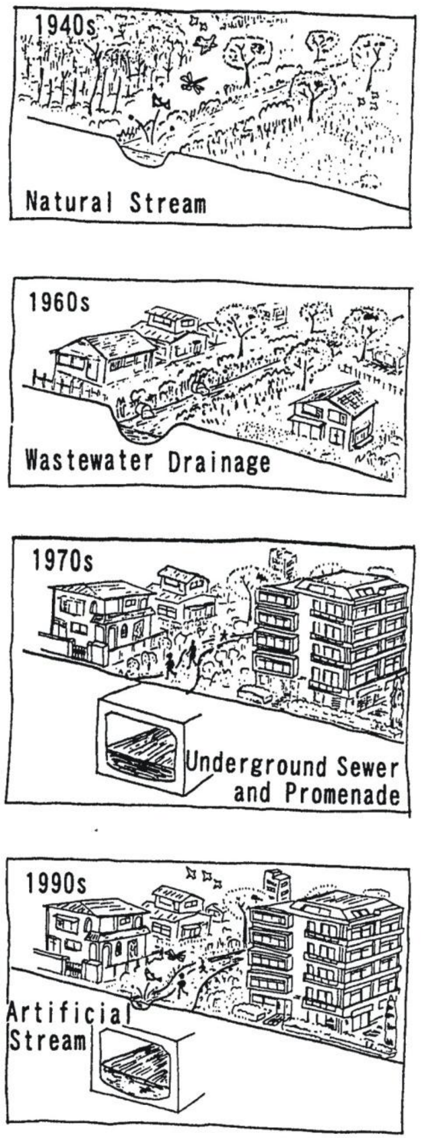
- With the high degree of treatment required in the new cities it does not make sense to use sewers for conveyance; they were invented and used for conveyance of highly polluted urban wastewater and urban runoff
- Streams covered, converted to culverts or combined sewers can be brought to the surface
- A new stream can be recreated in a place where the old stream is irreversibly lost



# KITAZAWA STREAM IN TOKYO

- Flow in the "upper" stream is provided by a highly treated effluent from a nearby treatment plant

- Fish is living in the stream and looks healthy




The history of Kitazawa Stream

Photo (left) by V. Novotny, drawing (above) courtesy Prof. Shoichi Fujita

# Zhuan River daylighting and restoration in Beijing

Before restoration

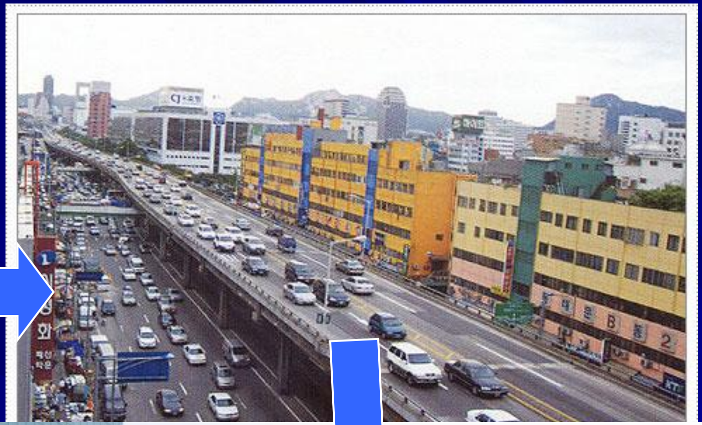
After restoration

Courtesy Beijing Hydraulic Research Institute




# Daylighting of old canals in Ghent, Belgium

# CheongGyeCheon (Seoul, KR)




## Benefits ++++

City revitalization, Aesthetic

Flood control, Ecology

## Sustainability -

No water reclamation, water is pumped from a larger river downstream, carbon negative

# Conclusions

- In the US and elsewhere, after the point s and a part of nonpoint sources of pollution were controlled, emphasis is now on restoration of aquatic ecosystems damaged by previous overuse
- Control of point and nonpoint pollution is a prerequisite for successful restoration
- Water body restoration is highly desired and appreciated by the citizens
- The impacts of restoration are great but gradual, it takes time for the system to heal