Transportation Impacts on Water Resources

Kumares Sinha and Samuel Labi
Purdue University School of Civil Engineering
This presentation ...

- Introduction
- Transportation Impacts on Water - How to categorize?
- Performance Measures for the Impact Assessment
- Overall Framework for Water Quality Impact Assessment
- How to Mitigate the Adverse Impacts
- Legislation
Introduction

Water …

- critical for sustaining human life
- vital for human activities (agric., domestic, industrial, etc.)
- Supports ecology (plants and animals)

Generally, transportation construction, maintenance, and operations cause negative impacts on:

- water quality
- water quantity
- natural patterns of water flow
The Hydrologic Cycle

- Describes the movement of water, at or below the Earth's surface and in the atmosphere.
Hydrologic Cycle – Key Processes

- **Evaporation** - conversion of water molecules into water vapor; released in vapor form into atmosphere.

- **Transpiration** - emission of water from plant leaves.

- **Condensation** – Result of rising and cooling of water vapor and eventual settlement on tiny particles of dust in atmosphere; water particles collect and form clouds.
Precipitation - Condensed water vapor droplets propelled by air currents from one place to another; upon cooling, become saturated with moisture and precipitate in the form of rain, snow or hail.

Runoff - flow of precipitated water over the earth’s land surface into rivers, creeks, ditches, etc.

Infiltration – percolation of surface rain water or snowmelt into the earth’s sub-surface through pores of exposed permeable soil and through cracks and joints in surface bedrock; ultimately reaches groundwater where it recharges the water table.
Categories of Hydrological Impacts

- **Source of the Impact (Facility/Vehicle)**
  - Transportation facility (guideway, parking lots/garages, terminals, airports, harbors, etc.)
  - Vehicles that use the facility (trucks, cars, planes, trains, ships, etc.)

- **Impact Type**
  - Impact on Water Quality
  - Impact on Water Course
  - Impact on Water Quantity

- **Affected Water Source**
  - Surface water
  - Ground water
  - Water (clouds) in the air

- **Transportation Mode**
  - Highways
  - Rail
  - Air, and
  - Marine transportation

- **Transportation Activity**
  - construction, operations, maintenance, and abandonment of infrastructure facilities,
Categories of Impact

1. Source of the Impact

- Transportation facility
  - Examples: guideway, parking lots/garages, terminals, airports, harbors, etc.
  - Affect mostly water quantities and flow paths
  - Cover large land area: less percolation, more run-off
  - Cause flooding and water deprivation

- Vehicles that use the facility
  - Examples: trucks, cars, planes, trains, ships, etc.
  - Affects mostly water quality
  - Water runoff cause water pollution
  - Manufacture/maintenance/operation/upkeep of vehicles involve large quantities of water
2. Type of the Impact

(a) Quality (Polluting or Degrading Effects)
   - Contamination of water that renders it unfit for use by humans or other living organisms.
   - **Physical** - impedance or acceleration of water flow leading to decreased or increased water availability, physical contact bet. pollutants and water, and subsequent spreading or mixing.
   - **Chemical** - reactions bet. pollutants and naturally-occurring chemicals in environment; pollutant-catalyzed reactions that would otherwise not take place.
   - **Biological** - disruption of ecological patterns; affect quantity or quality of ground or surface water bodies.

(b) Impact on Water Quantity (Deprivation Effects)
   - redirection of the water within or across hydrologic processes that leads to too little water available to humans and organisms for consumption at one location, and/or too much water (flooding) at other locations, possibly causing loss of life or property.

(c) Impact on Water Course (Flow Pattern Effects)
   - change in the natural paths of water flow either within a hydrologic phase or in moving from one hydrologic phase to another. Thus disrupts the ecology.
3. What type of Water Source is Affected?

(a) Surface Water
- Rivers, creeks, streams, lakes, lagoons, etc.
- Generally more vulnerable to transportation impacts, either through reduced quality, quantity, or disruption of natural flow patterns.

(b) Groundwater
- Relatively less vulnerable to transportation activities
- More difficult to identify and mitigate when they occur

(c) Water in the air
- Vulnerable to air transportation operations
- Also, more difficult to identify and mitigate when they occur
<table>
<thead>
<tr>
<th>Transportation Activities</th>
<th>Nature of Impact</th>
</tr>
</thead>
</table>
| Construction and Maintenance of Pavements, Bridges, Tunnels, and Parking Garages and Lots | Embankments and cut sections cause retraining of surface water courses thus disrupting natural flow patterns of surface water  
Dust and sediments released during construction and maintenance pollute water bodies  
Transport of deicing compounds (rock salt) into surface water bodies  
Transport of solid matter through highway runoff into surface water bodies |
| Manufacture of Motor Vehicles and Parts | Toxic releases and other emissions during manufacture  
Direct use of water in vehicle manufacture |
| Highway Operations (Road Vehicle Travel) | Hazardous material spills during transport  
Tailpipe and evaporative emissions  
Fugitive dust emissions from roads  
Emissions of refrigerant agents from vehicle air conditioners  
Road surface debris from motor vehicles and road users that are washed by run-off into streams |
| Maintenance of Motor Vehicles | Contaminant releases during terminal operations: tank truck cleaning, maintenance, repair, and refueling  
Contaminant releases during passenger vehicle cleaning, maintenance, repair, and refueling  
Leaking underground storage tanks containing petroleum products  
Use of water for vehicle washing |
| Disposal of Motor Vehicles and Parts | Scrappage of vehicles  
Improper disposal of motor oil and other vehicle fluids  
Disposal of tire, lead-acid batteries, and other consumables |
## Categories of Impact

**Mode - Rail**

<table>
<thead>
<tr>
<th>Transportation Activities</th>
<th>Nature of Impact</th>
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</thead>
<tbody>
<tr>
<td>Construction and Maintenance of Railway Tracks and Bridges</td>
<td>Emissions during construction and maintenance</td>
</tr>
<tr>
<td>Manufacture of Rail Cars and Parts</td>
<td>Toxic releases and other emissions during manufacture</td>
</tr>
<tr>
<td>Rail Transportation Operations (Rail Travel)</td>
<td>Exhaust emissions</td>
</tr>
<tr>
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<td>Spillage of hazardous materials during transport incidents</td>
</tr>
<tr>
<td>Maintenance and Support Operations for Rail Cars</td>
<td>Releases during terminal operations: car cleaning, maintenance, repair, and refueling</td>
</tr>
<tr>
<td></td>
<td>Emissions from utilities that provide power for rail</td>
</tr>
<tr>
<td>Disposal of Rail Cars and Parts</td>
<td>Rail car and parts disposal</td>
</tr>
<tr>
<td></td>
<td>Abandonment of rail tracks</td>
</tr>
<tr>
<td>Transportation Activities</td>
<td>Nature of Impact</td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Construction, Maintenance, or Expansion of Airports or Runways</td>
<td>Emissions during construction and maintenance</td>
</tr>
<tr>
<td></td>
<td>Releases of deicing compounds</td>
</tr>
<tr>
<td></td>
<td>Airport runoff</td>
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<tr>
<td>Manufacture of Aircraft and Parts</td>
<td>Toxic releases and other emissions during manufacture</td>
</tr>
<tr>
<td>Air Transportation Operations (Aviation Travel)</td>
<td>High altitude emissions</td>
</tr>
<tr>
<td></td>
<td>Low altitude/ground level emissions</td>
</tr>
<tr>
<td></td>
<td>Hazardous materials incidents during transport</td>
</tr>
<tr>
<td>Airport Facility Operations</td>
<td>Emissions from ground support equipment involved in aircraft loading, cleaning,</td>
</tr>
<tr>
<td></td>
<td>maintenance, repair, and refueling</td>
</tr>
<tr>
<td>Disposal of Aircraft and Parts</td>
<td>Airplane and parts disposal</td>
</tr>
</tbody>
</table>
### Categories of Impact

**Mode – Marine**

<table>
<thead>
<tr>
<th>Transportation Activities</th>
<th>Nature of Impact</th>
</tr>
</thead>
</table>
| Construction and Maintenance of Marine Navigation Infrastructure | Direct deterioration of water quality from dredging or other navigation improvements  
Contamination from disposal of dredged material                   |
| Manufacture of Maritime Vessels and Parts                      | Toxic releases during manufacture                                                 |
| Maritime Transportation Operations (Vessel Travel)              | Nitrogen oxide and sulfur oxide emissions by vessel engines  
Hazardous materials spills during transport  
Overboard dumping of solid waste and sewage  
Release of ballast water containing alien species               |
| Maritime Vessel Maintenance and Support                         | Anti-fouling chemicals to prevent biological growth on vessel hulls during terminal operations |
| Disposal of Maritime Vessels and Parts                          | Scrappage of old vessels and dilapidated parts                                   |
Performance Measures for Water Impact Assessment

Performance Measures

- Water Quantity
- Water Quality
- Water Flow Paths and Patterns
Performance Measures for Water Impact Assessment

Performance Measures Related to Water Quantity and Flow Patterns

- **Aquifer Safe Yield**: difference between the rate of withdrawal and the rate of recharge.

- **Flow Variations**: change in velocity of flow (ft/s) or rate of discharge (ft³/s).
Measures Related to Water Quality

(a) **Oil Contamination** - Oil is a petroleum product that is discharged from transportation vehicles and vessels and reaches surface waters either directly or through run-off where it spreads out on the water surface.

(b) **Suspended Solids** - Insoluble solid contaminants remain suspended in water, causing turbidity.

(c) **Acidity and Alkalinity** - pH assessment is an important indicator of environment quality. High pH value signifies an alkaline condition while low pH value represents an acid condition with neutral condition having a pH value of 7.0.

(d) **Biochemical Oxygen Demand (BOD)** - BOD of water is a direct bioassay measure of the amount of oxygen required for biological decomposition of organic matter in the water body.
(e) **Dissolved Oxygen (DO)** - All life form directly or indirectly need oxygen to live. The lack of DO will generate anaerobic conditions resulting in unfavorable odor and visual appearance.

(f) **Dissolved Solids** - A high level of total dissolved solids degrades water quality as they alter the physical and chemical characteristics of the water and exert osmotic pressure on organisms living in such waters.

(h) **Toxic compounds** - Wastes that contain heavy metals (mercury, copper, silver, lead, nickel, cobalt, arsenic, cadmium, chromium), ammonium compounds, cyanides, sulfides, fluorides, and petrochemical wastes.

(g) **Nutrients** - Eutrophication, the process whereby waters bodies are supplemented with nutrients (such as phosphorus and nitrogen) through human activity (fertilizers) or natural resources (erosion of soil containing nutrients).
Describe the Proposed Changes in the Selected Transportation System Action

Carry out a Hydrological Inventory of the Study Area

Step 1
Define the Study Area and Temporal Scope

Describe the Proposed Changes in the Selected Transportation System Action

Step 3

Identify the TDP Phases of the Transportation Action that are likely to affect the Area Hydrology

Step 4
Select the Appropriate Hydrological Performance Measures

Step 5

Data Analysis to Predict Hydrological Conditions after the Transportation Intervention

Step 6

The Base Case Scenario (No Transportation Intervention)

Step 2
Carry out a Hydrological Inventory of the Study Area

Step 7

Estimate the Hydrological Impacts (Change in Hydrological Performance Measures)

Step 8
Evaluate the Predicted Hydrological Impacts

The Transportation Intervention Scenario

Methodology For Water Impact Assessment
Methodology For Water Impact Assessment

1. Define the Study Area and Temporal Scope

2. Carry out a Hydrological Inventory of the Study Area

3. Describe the Proposed Changes in the Selected Transportation System Action

4. Identify the TDP Phases of the Transportation Action that are likely to affect the Area Hydrology

5. Select the Appropriate Hydrological Performance Measures

6. Data Analysis to Predict Hydrological Conditions after the Transportation Intervention

7. Estimate the Hydrological Impacts (Change in Hydrological Performance Measures)

8. Evaluate the Predicted Hydrological Impacts

The Base Case Scenario (No Transportation Intervention)

The Transportation Intervention Scenario
Methodology For Water Impact Assessment

**The Base Case Scenario (No Transportation Intervention)**

1. **Step 1**: Define the Study Area and Temporal Scope

2. **Step 2**: Carry out a Hydrological Inventory of the Study Area

3. **Step 3**: Describe the Proposed Changes in the Selected Transportation System Action

4. **Step 4**: Identify the TDP Phases of the Transportation Action that are likely to affect the Area Hydrology

5. **Step 5**: Select the Appropriate Hydrological Performance Measures

6. **Step 6**: Data Analysis to Predict Hydrological Conditions after the Transportation Intervention

7. **Step 7**: Estimate the Hydrological Impacts (Change in Hydrological Performance Measures)

8. **Step 8**: Evaluate the Predicted Hydrological Impacts

**The Transportation Intervention Scenario**

Water quantity
Water quality
Flow paths/patterns
Focus on Steps 6 and 7
(Methods for Predicting Transportation Impacts on Water)

**Impacts on Water Quantity**

- Methodologies differ by the nature of affected water source, impact category, and performance measure.
- Automated in the form of computerized modeling software.

(a) Predicting Impacts on Surface Run-off Quantities

(i) The Fundamental Run-off Formula

Involves a balance between hydrological inputs and outputs to surface run-off over a fixed time period:

\[
\text{Run-off} = \text{Precipitation} - \text{Evapotranspiration} - \text{Infiltration} - \text{Storage}
\]

(ii) The Rational Formula

\[
Q_p = ciA
\]

- \(Q_p\) = peak discharge (ft3/sec);
- \(A\) = drainage area (acre);
- \(c\) = runoff coefficient,
- \(i\) = rainfall intensity (in/hr) for a storm duration
Large intermodal transp. transfer facility planned at city outskirts: 30-acre wooded area
15% to be converted to concrete parking lots and streets,
5% - lawns (average lawns with 2-7% heavy soil)
2% - roofs of the facility buildings and shelters
Estimate expected change in run-off volume due to the new facility.
Assumptions:
Entire drainage area can be considered as a single drainage unit.
Times of concentration: 30 and 18 mins before and after project, respectively
Return period - 10 yrs.
The rainfall intensity function for the region is:  \[ i = \frac{2.1048 \times T^{0.1733}}{(t_c / 60 + 0.47)^{1.1289}} \]
Use the midpoints of run-off coefficient ranges shown in table below.

<table>
<thead>
<tr>
<th>Description</th>
<th>Before Project</th>
<th>After Project</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area I</td>
<td>Area II</td>
</tr>
<tr>
<td></td>
<td>Wooded Area</td>
<td>Concrete Streets</td>
</tr>
<tr>
<td>Area, A</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>Runoff Coefficient, C</td>
<td>0.15</td>
<td>0.825</td>
</tr>
<tr>
<td>Rainfall Intensity, i</td>
<td>3.25</td>
<td>3.25</td>
</tr>
<tr>
<td>Run-off from each Area</td>
<td>14.625</td>
<td>0</td>
</tr>
<tr>
<td>Total Run-off</td>
<td>14.63</td>
<td></td>
</tr>
</tbody>
</table>
Solution

\[ i_{before} = \frac{2.1048 \times 10^{0.1733}}{(30 / 60 + 0.47)^{1.1289}} = 3.25 \]

After construction, the rainfall intensity is:

\[ i_{after} = \frac{2.1048 \times 10^{0.1733}}{(18 / 60 + 0.47)^{1.1289}} = 4.21 \]

Change in run-off volume = 33.82 – 14.63 = 19.19 ft\(^3\)/sec.

Thus the project resulted in a 131% increase in surface run-off quantity.
(b) Models that Predict Changes in Water Flow Patterns

- Hydrodynamic models (equations that describe the movement of water)
  - derived from the three-dimensional Navier-Stokes equations
  - applied in the before and after transportation activity scenarios to establish any differences in water flow patterns.

(c) Models that Predict Changes in Groundwater Quantity

- Darcy's Law
  - states that the flow of fluid through a saturated porous medium (for example, water through an aquifer) is dependent on the hydraulic gradient (change in piezometric head over a distance) and the hydraulic conductivity (permeability) of the medium

\[
Q = K \times A \times \left( \frac{\partial H}{\partial L} \right)
\]

- \(Q\) = total discharge/flow (m³/day), \(K\) = permeability or hydraulic conductivity (m/day), \(A\) = cross-sectional area to flow (m²), and \(H/L\) = hydraulic gradient
Example

Planned underground subway terminal traverses hydrologically sensitive site (site contains unconfined aquifer that supplies city’s water supply.

Estimated 7% of aquifer cross sectional area to be taken up.

Calculate expected % reduction in groundwater flow due to the proposed construction.

Prior tests indicate the following underground conditions:

- Fractured rock material \((K = 1,000 \text{ ft/day})\)
- Hydraulic gradient = 0.05.

Assume that after the construction, the permeability of the medium is reduced by 10% but the hydraulic gradient remains unchanged.
(d) Models that Predict Impacts on Water Quality

The mass (or material) balance equation

Mass that entering a system must either leave the system or accumulate within the system through the conservation of mass principle.

The rate of change in total contaminant mass in a compartment over time is:

\[ \frac{dM}{dt} = I + D + F + J = X + R + T \]

Where:
- \( I \) = mass inflow rate into the compartment (mass/time),
- \( D \) = discharge into the compartment (mass/time),
- \( F \) = mass formation rate due to biochemical activity in the compartment (mass/time),
- \( J \) = transfer from other compartments (mass/time),
- \( X \) = outflow from the compartment (mass/time),
- \( R \) = degrading reaction (mass/time), and
- \( T \) = transfer to other compartments (mass/time).
Accumulated pollutant load model

○ Function of initial load, accumulation rate, length of highway and duration of accumulation.

\[ P = P_0 + K_1 H_L T \]

○ Where

- \( P \) = load of pollutant after accumulation (lb/acre/event),
- \( P_0 \) = load of pollutant before accumulation (lb/acre/event),
- \( K_1 \) = accumulation rate (lb/mile/day) = \( 0.007 \times \) (Average Daily Traffic, ADT)^0.89,
- \( H_L \) = length of highway (mile),
- \( T \) = duration of accumulation (day)
Example

State road (13,000 ADT) to be converted into a 10-mile urban freeway (30,000 ADT expected).

Duration of accumulation:
-12 hrs for state road
- 18 hrs (expected) for freeway.

Load of pollutant before accumulation = 500 lb/acre. Calculate the expected change in pollutant loads after project completion.
Load of pollutant, after accumulation, $P$ of the roads are as follows:

$$P = P_0 + K_1 H_L T$$

Before the improvement (state road):
$$P = 500 + 0.007(13,000)^{0.89} \times 10 \times (12/24) = 660.5 \text{ lb/acre}$$

After the improvement (freeway):
$$P = 500 + 0.007(30,000)^{0.89} \times 10 \times (18/24) = 1006.8 \text{ lb/acre}$$

Expected percentage change in pollutant load:
$$= (1006.8 - 660.5)/660.5 = 52.4\%$$
1. Mitigation Measures by Nature of Water Source

- **Groundwater**
  - Investigate the groundwater hydrology at or near alternative project locations, and final project location could be chosen in order to minimize adverse effects.
  - Lagooning of oil wastes and land disposal of oily sludges should be restricted or controlled.

- **Water flow variations**
  - Transportation activities that are related to land use changes and water impoundments and operations should be duly considered to minimize post-project water flow variations from the mean natural flow quantities and directions.

- **Surface Runoff**
  - All surface runoff around mines or quarries should be collected and concentrated. The brine may be disposed of by deep well injection or other means acceptable to water quality control authorities.
  - Control all direct discharge into natural waters.
2. Mitigation Measures by TDP Phase

- **Location Planning**: Avoid areas sensitive to water resources impacts

- **Design**: Design appropriate hydraulic structures.

- **Construction**: Proper erosion control and disposal of construction waste.

- **Operations**: Proper disposal used transportation vehicles and their parts.

- **Maintenance**: Proper use and disposal of toxic materials during maintenance.
Water Quality Standards

- Established by United States EPA
- Publishes its national recommended water quality criteria for the protection of aquatic communities, wildlife, and human health.
- These criteria are developed on the basis of requirements established by Section 304(a)(1) of the Clean Water Act.
- These criteria provide guidelines for each state or tribe for the development of their general or site-specific water quality standards.
- Site: http://www.epa.gov/waterscience/criteria/
Legislation related to Water Resource Conservation

- **National Environmental Policy Act (1969)** - requires all agencies to assess the environmental impact of implementing any project requiring federal actions.

- **Wild and Scenic Rivers Act (1969)** - establishes the Wild and Scenic River System and protects rivers designated for their wild and scenic values from activities which may adversely affect those values.

- **Clean Water Act (1972)** - aimed at restoring and maintaining the chemical, physical, and biological integrity of natural water resources.

- **Others**
  - Marine Protection, Research, and Sanctuaries Act (1972), Coastal Zone Management Act (1972),
  - Section 404 Regulatory Program (1972)
  - Safe Drinking Water Act (1974)
  - Resource Conservation and Recovery Act (1976)
  - Superfund Amendments and Reauthorization Act (1986)
  - Pollution Prevention Act (1990)
Software Packages

- The USDA’s Simulator for Water Resources in Rural Basins-Water Quality (SWRRBWQ)
  - predict the effect of management decisions on water, sediment, and pesticide yield.
  - Processes considered include surface run-off, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, sedimentation, and crop growth.

- Other Software Packages
  - Most of computer-based models were developed and are maintained by
    - USACE WES (US Army Corps of Engineers Waterways Experiment Station)
    - the USEPA (Environmental Protection Agency) Center of Exposure Assessment Modeling (CEAM)
    - Center for Subsurface Modeling Support (CSMoS)
  - Information and copies of these can be obtained at
    - http://el.erdc.usace.army.mil/
    - http://www.epa.gov/ceampubl/
    - http://www.epa.gov/ada/csmos.html
Questions?