Towards Sustainable Water Management in Industrial Cities

Sabla Alnouri, Patrick Linke, Mahmoud El-Halwagi

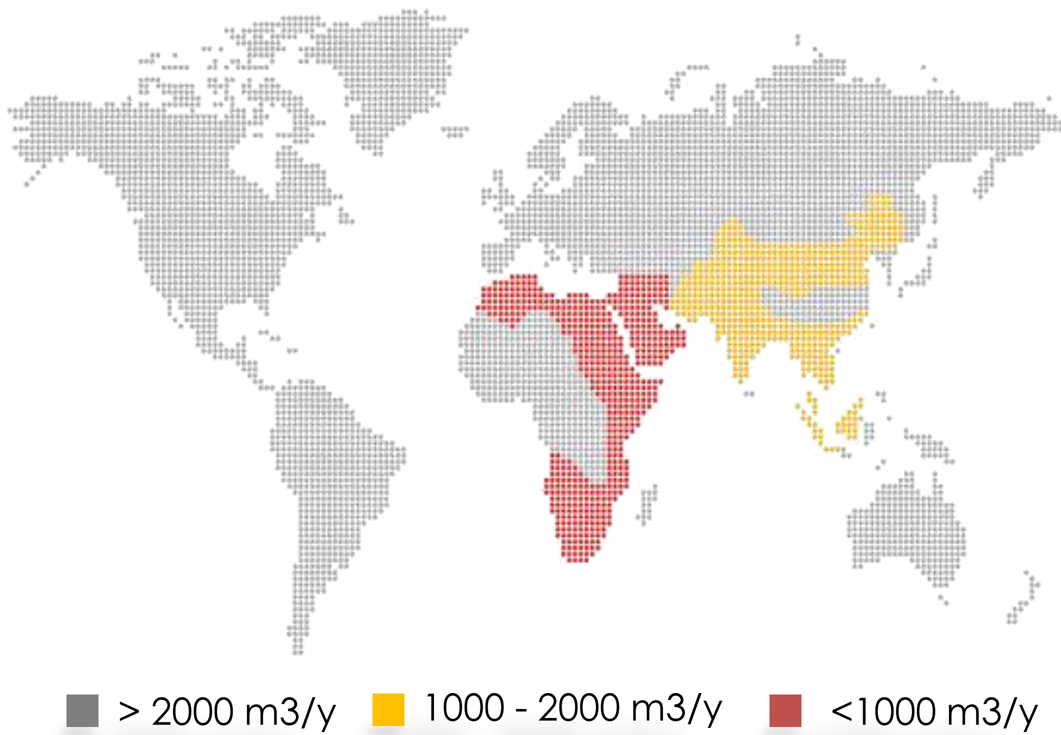
Energy & Water Security Workshop
Hamad Bin Khalifa University, Doha, Qatar
16th February 2015

INTRODUCTION

WATER SCARCITY

Two-thirds of the world's population in 2025 predicted to be under water stressed conditions

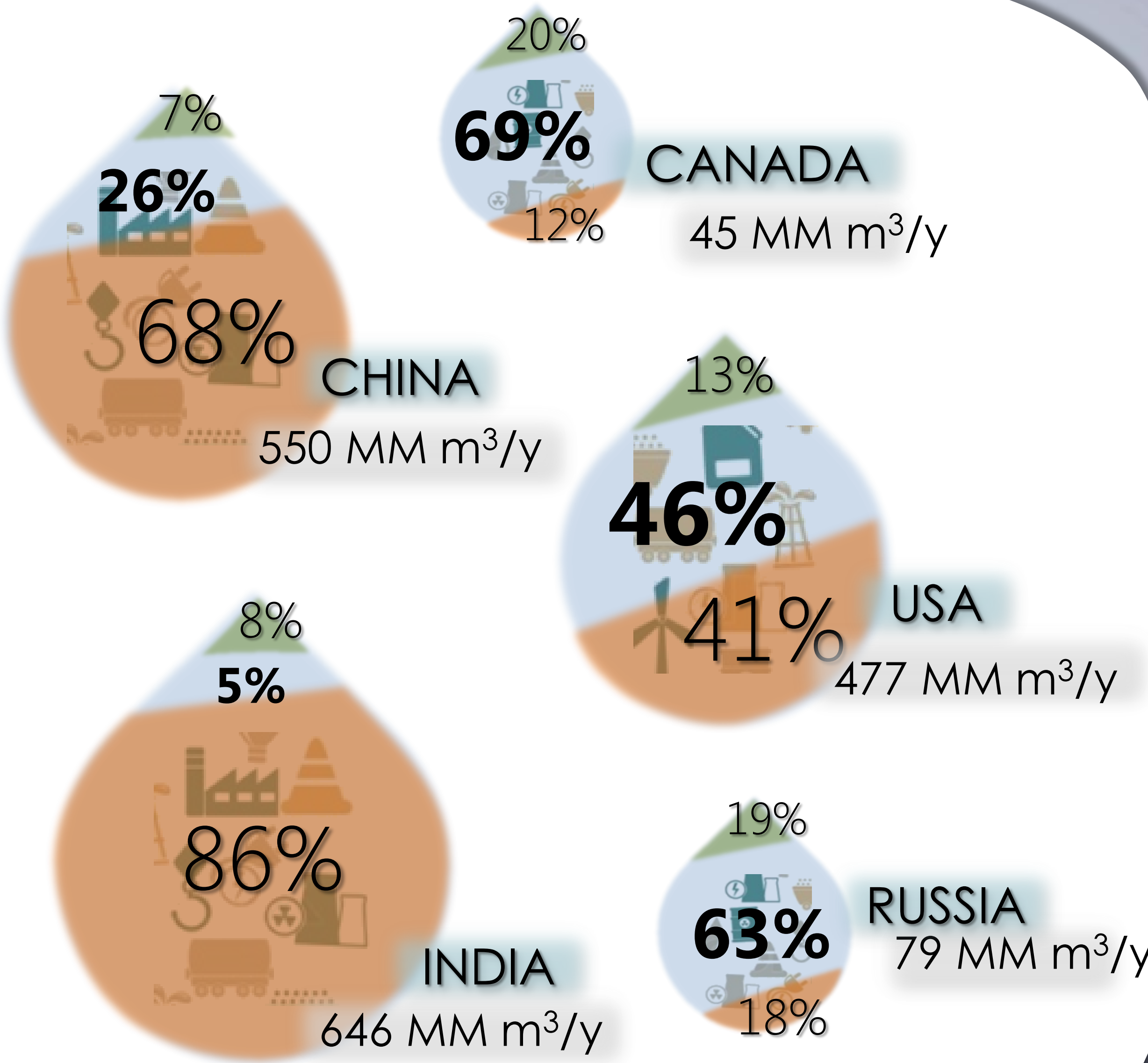
Maplecroft water index identifies Bahrain, Qatar, Kuwait and Saudi Arabia as world's most water stressed countries



Source: http://www.carnegiewave.com/index.php?url=/ceto/global-water

INTRODUCTION

FRESHWATER RESERVES AND WATER USE BY SECTOR

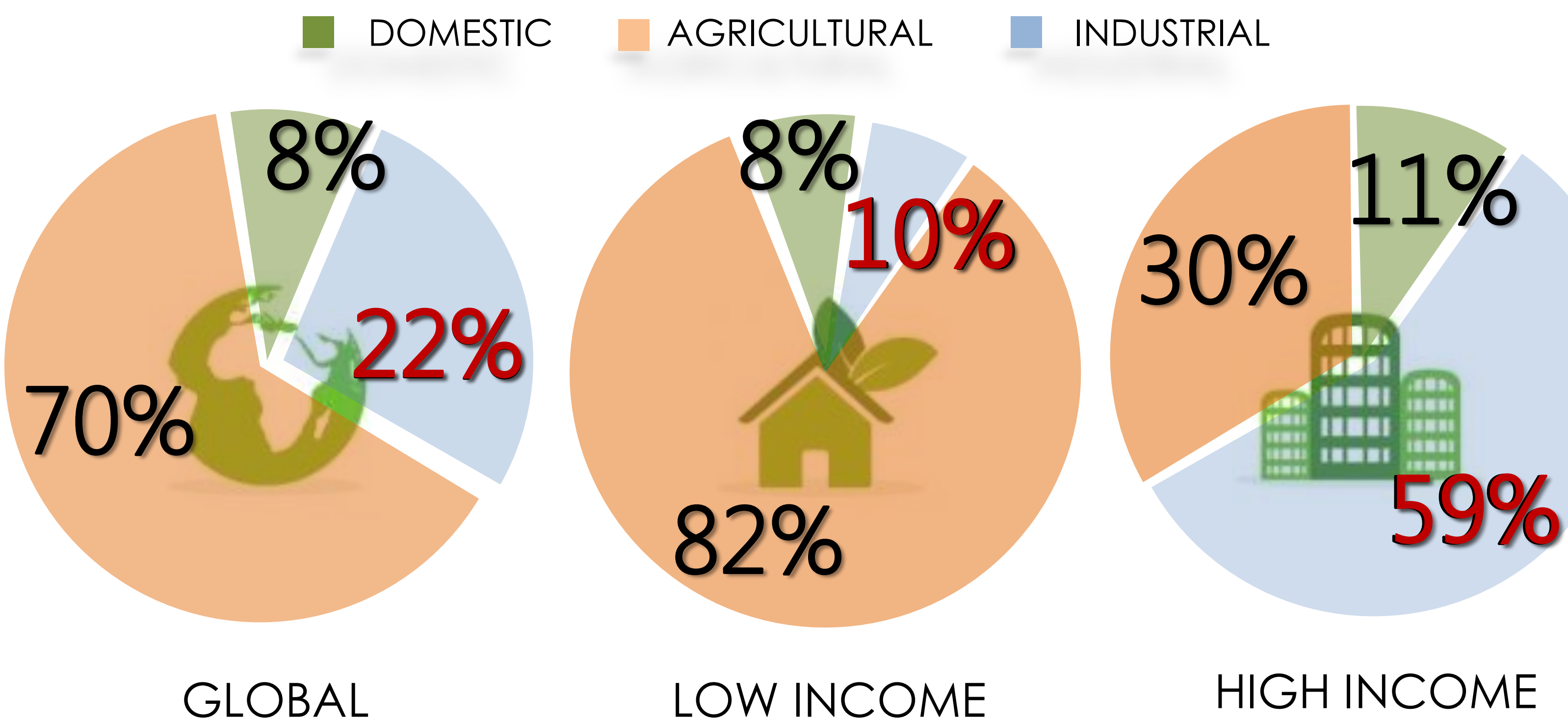


- DOMESTIC
- AGRICULTURAL
- INDUSTRIAL

Sources: Natural Land and Water Resources Audit; Ministry of Water Resources China; FAQ aquastat; US Geological Survey

INTRODUCTION

GLOBAL, LOW INCOME & HIGH INCOME COUNTRY WATER USE BY SECTOR



Source: cseindia.org/dte-supplement/industry20040215/agriculture.htm

INDUSTRIAL WATER USE

Cooling Towers

Process Operation

Cleaning and Maintenance

Boilers

Office Potable Water

Fire Fighting

Irrigation

WATER CONSUMPTION IN INDUSTRY

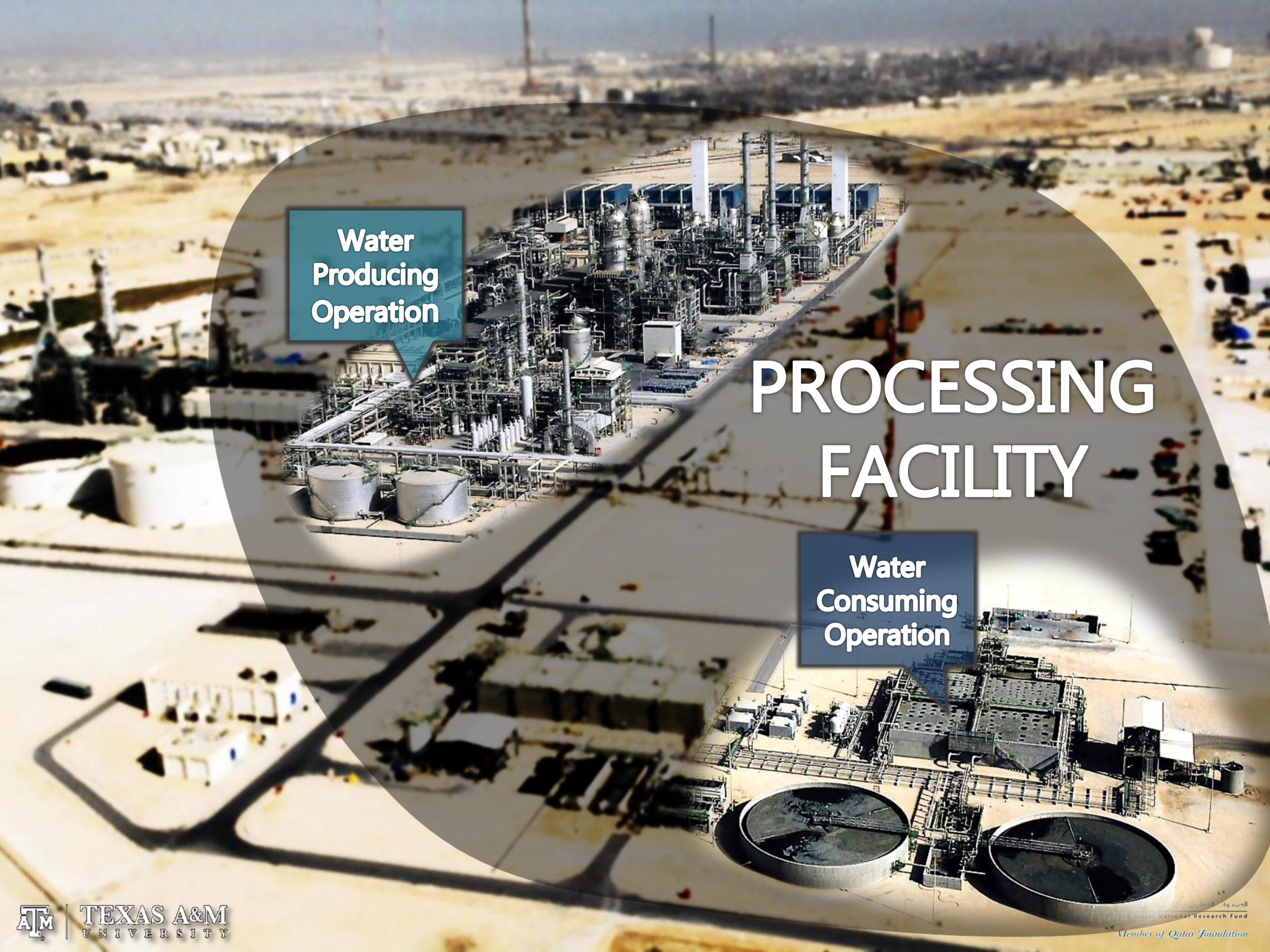
INDUSTRIAL WATER USE

FRESH WATER

- SEAWATER →
- DESALINATED WATER →
- SURFACE WATER →

→ WASTEWATER

WATER CONSUMPTION IN INDUSTRY


Water Producing Operation
PROCESSING FACILITY
Water Consuming Operation
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FRESHWATER
PROCESSING
FACILITY
OPERATION 1
OPERATION 2
OPERATION 3
WASTEWATER
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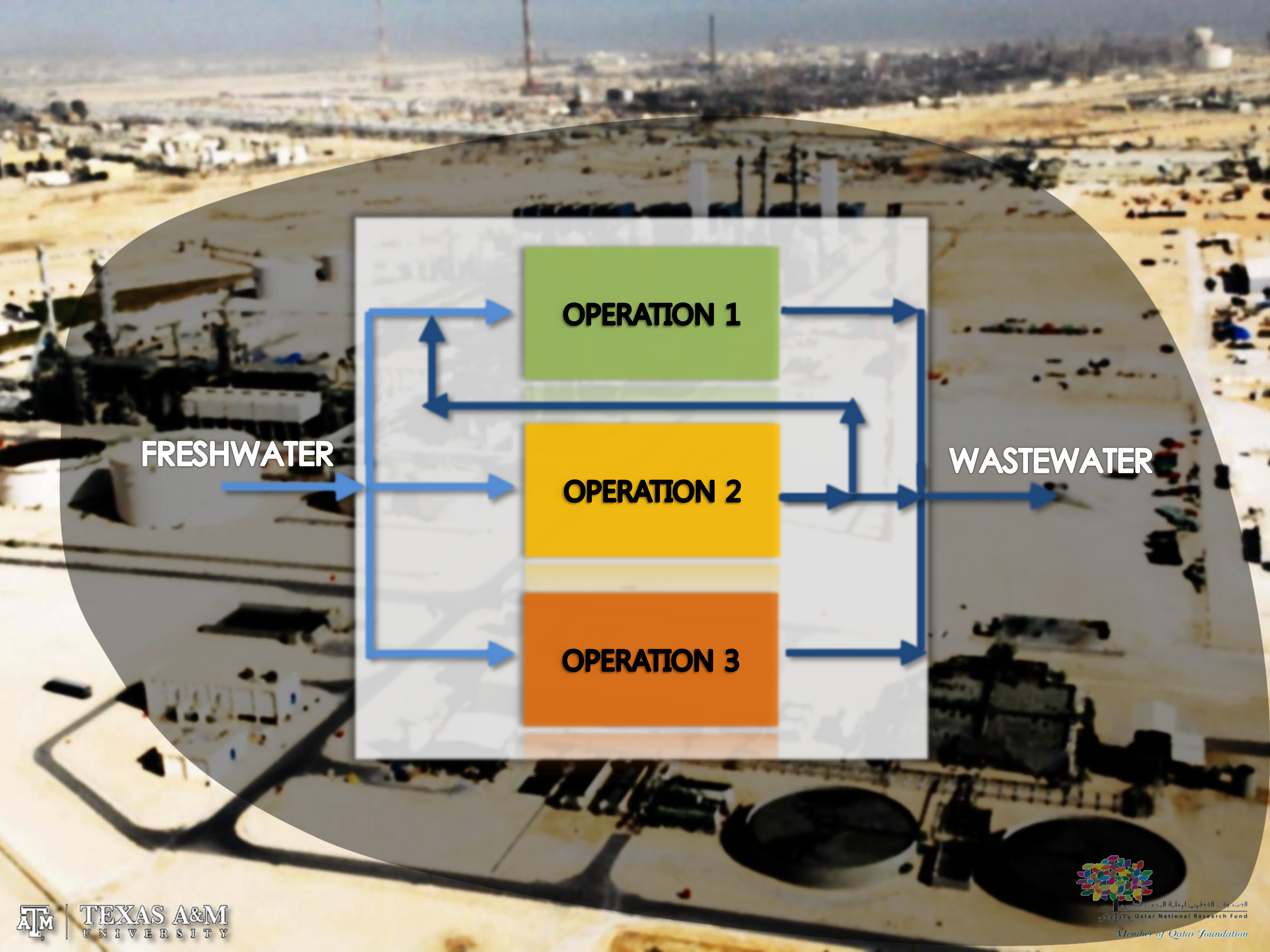
FRESHWATER
OPERATION 1
OPERATION 2
OPERATION 3
WASTEWATER
TEXAS A&M UNIVERSITY
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FRESHWATER
OPERATION 1
OPERATION 2
OPERATION 3
WASTEWATER
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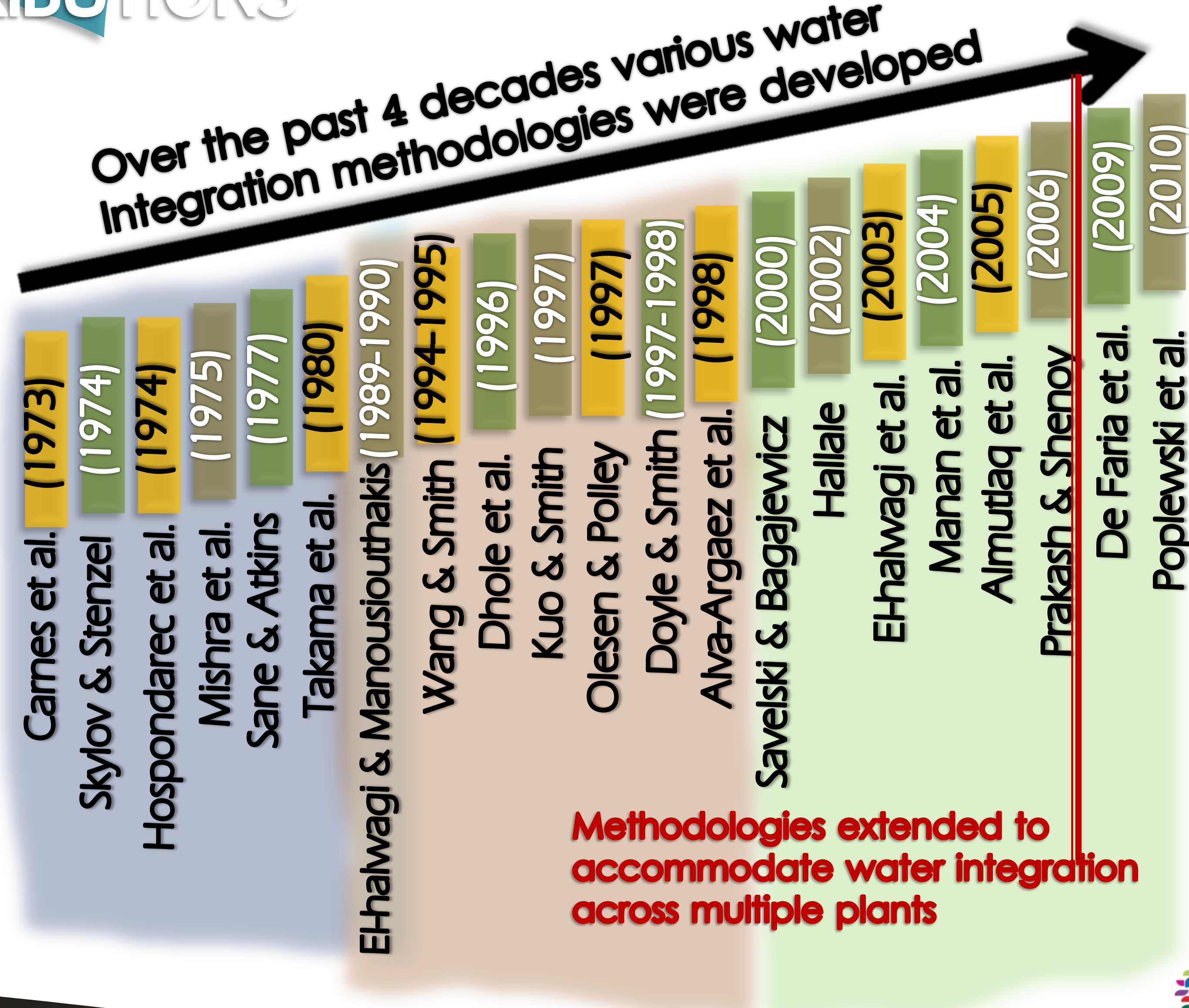
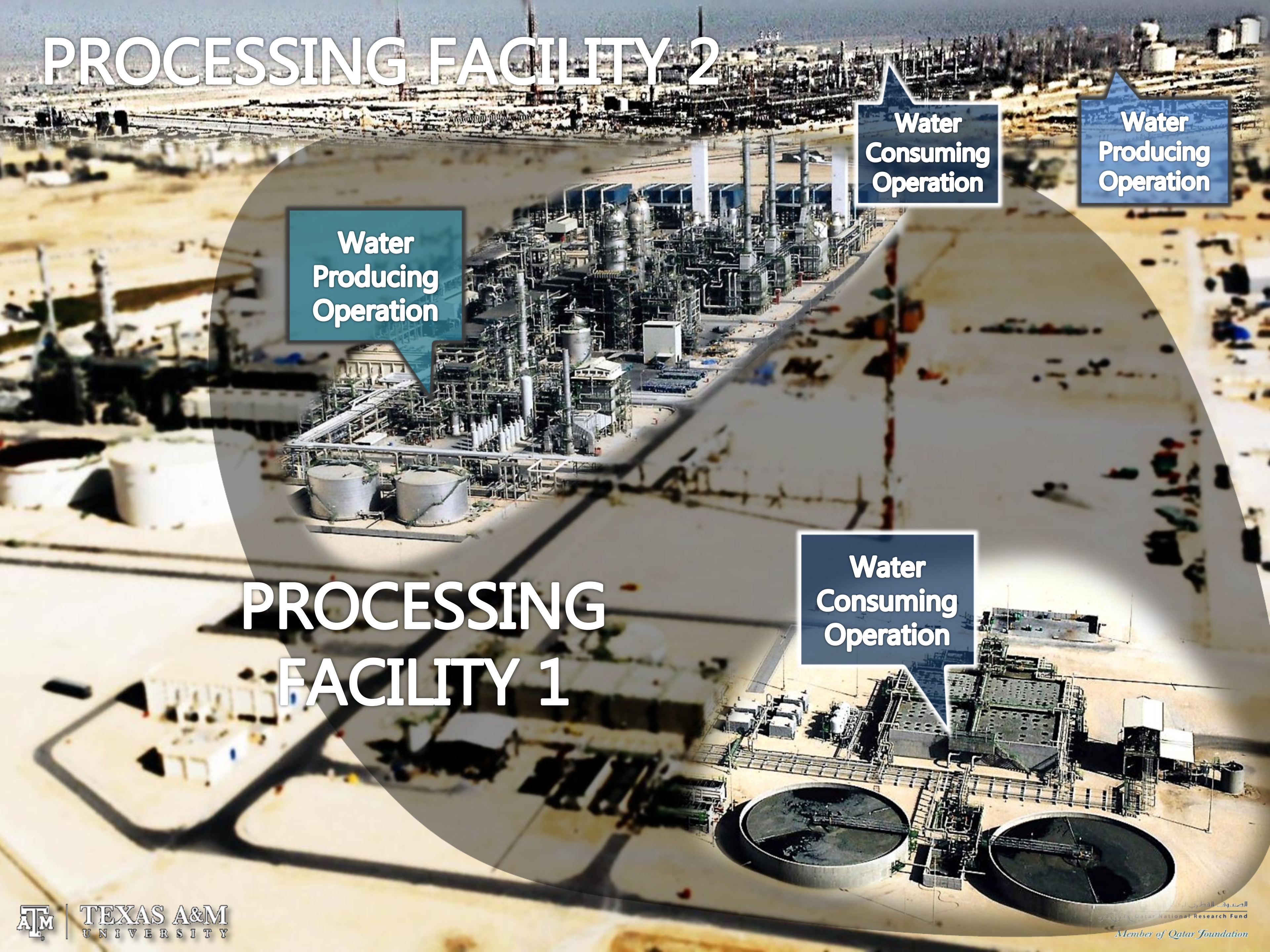
PREVIOUS CONTRIBUTIONS




PROCESSING FACILITY 2
Water Consuming Operation
Water Producing Operation
Water Producing Operation
PROCESSING FACILITY 1
Water Consuming Operation
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MACROSCOPIC FRAMEWORK

MACROSCOPIC FRAMEWORK

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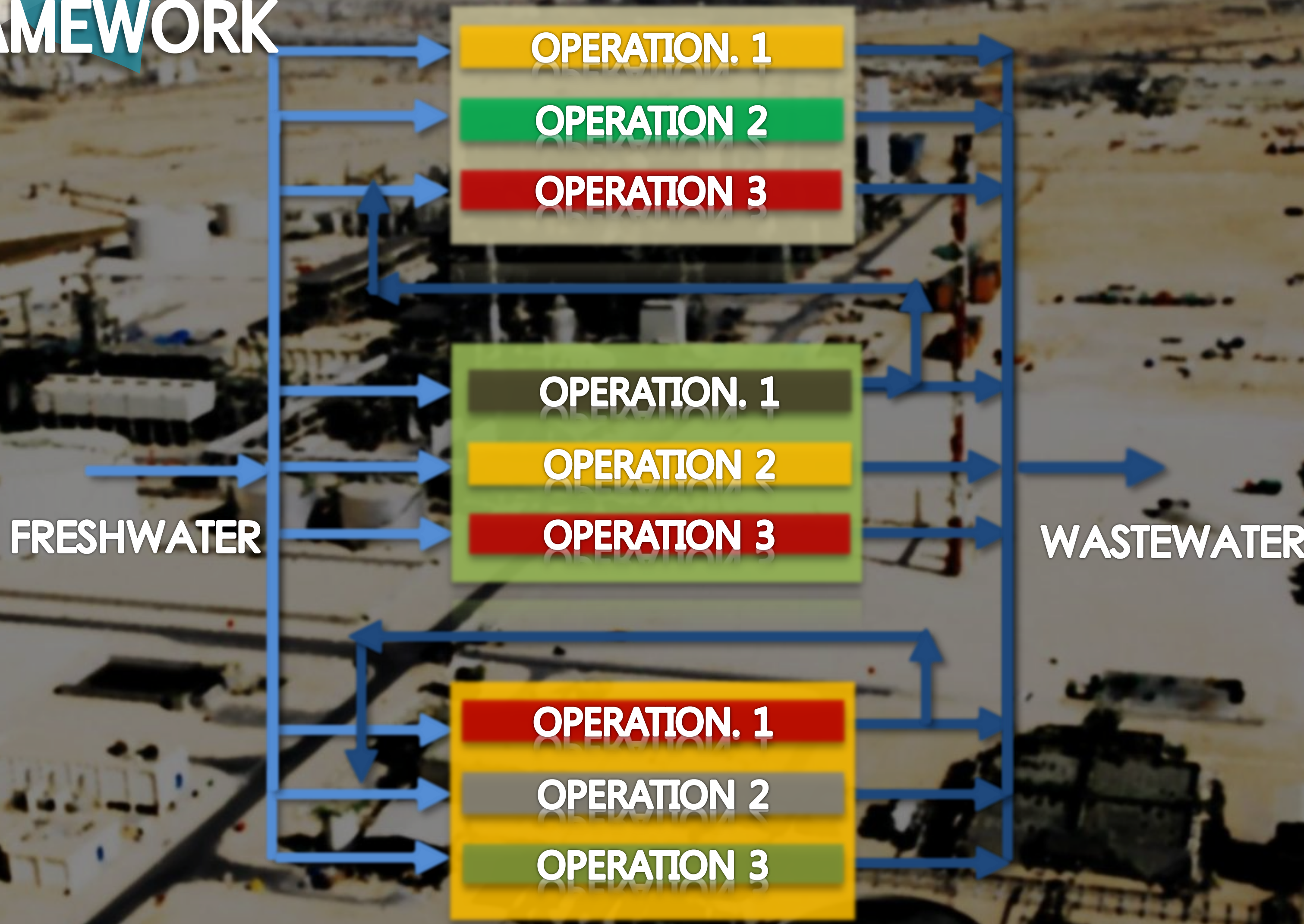

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PREVIOUS CONTRIBUTIONS

Over the past 5 years

- Chew et al. (2008)
- Lovelady & El-Halwagi (2009)
- Aviso et al. (2010)
- Kim et al. (2010)
- Chew et al. (2010)
- Lim et al. (2010)
- Rubio Castro et al. (2010)
- Boix et al. (2012)

CURRENT LIMITATIONS OBSERVED:

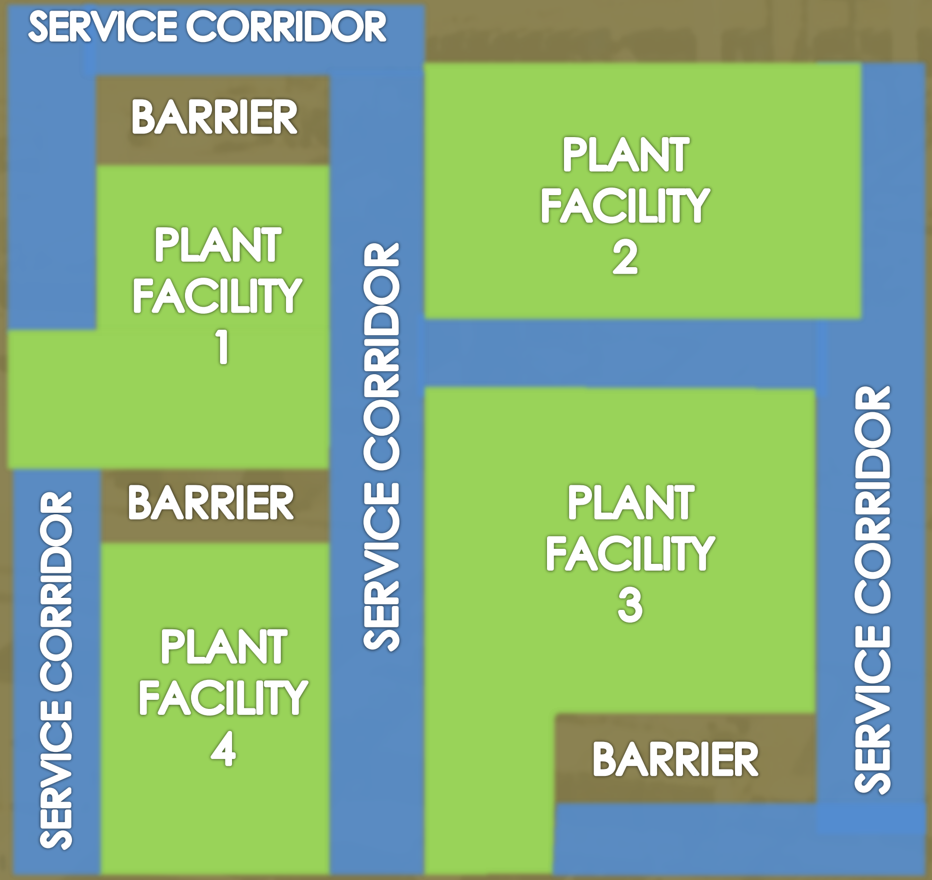
- Inability to capture spatial dimensions within a given plot
- Corridors and barriers amongst plants are therefore not accounted for
- Oversimplification of piping and connectivity
- Pressure drop calculations often neglected

MAIN ASPECTS ADDRESSED IN THIS RESEARCH

1. CAPTURING A SPATIAL REPRESENTATION FOR INDUSTRIAL CITIES
2. ADDRESSING INTERCONNECTIVITY IN WATER NETWORK DESIGN (PIPELINE MERGING)
3. INTRODUCING CENTRALIZED & DECENTRALIZED TREATMENT OPTIONS

INDUSTRIAL CITY
SPATIAL REPRESENTATION

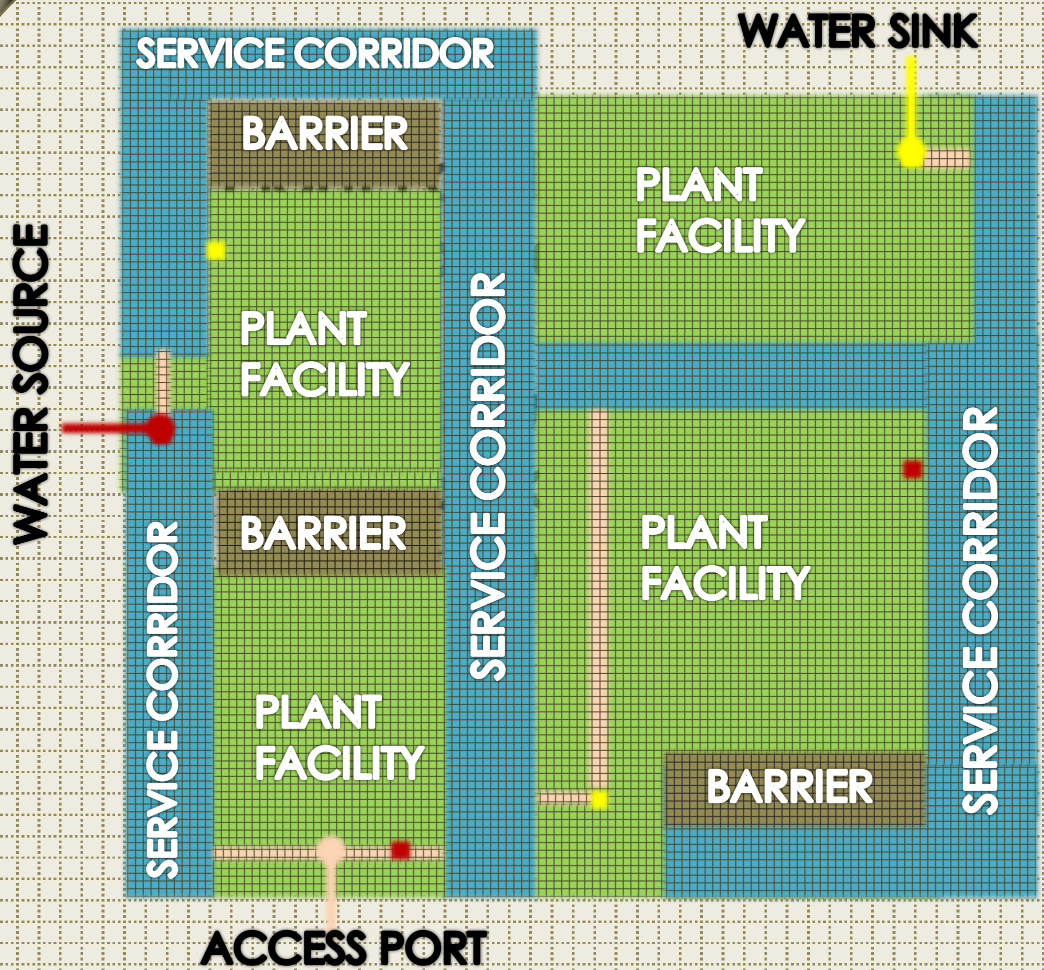
SPATIAL FRAMEWORK



Alnouri S., Linke P., El. Halwagi M.M, 2014, Water Integration in Industrial Zones – A Spatial Representation with Direct Recycle Applications, Clean Techn Environ Policy, DOI 10.1007/s10098-014-0739

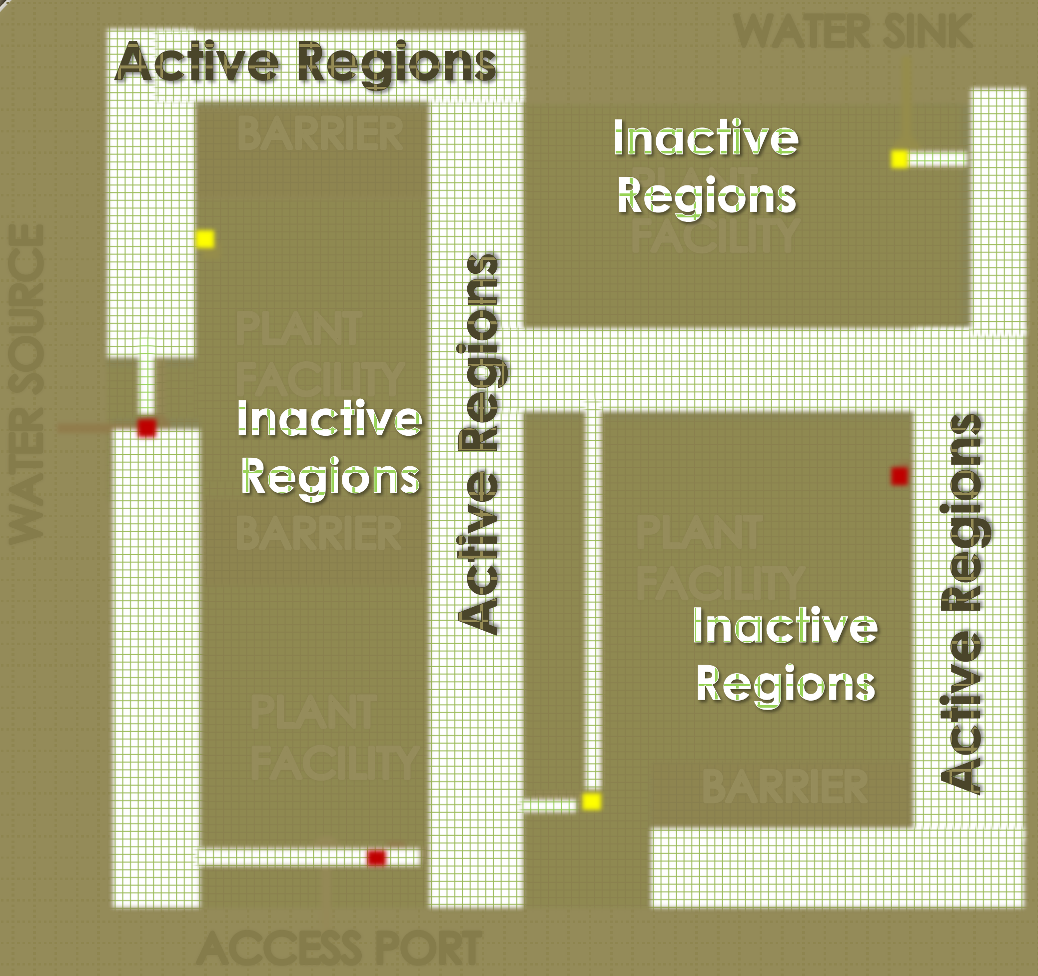
DIRECT RECYCLING + WATER TREATMENT

SPATIAL FRAMEWORK



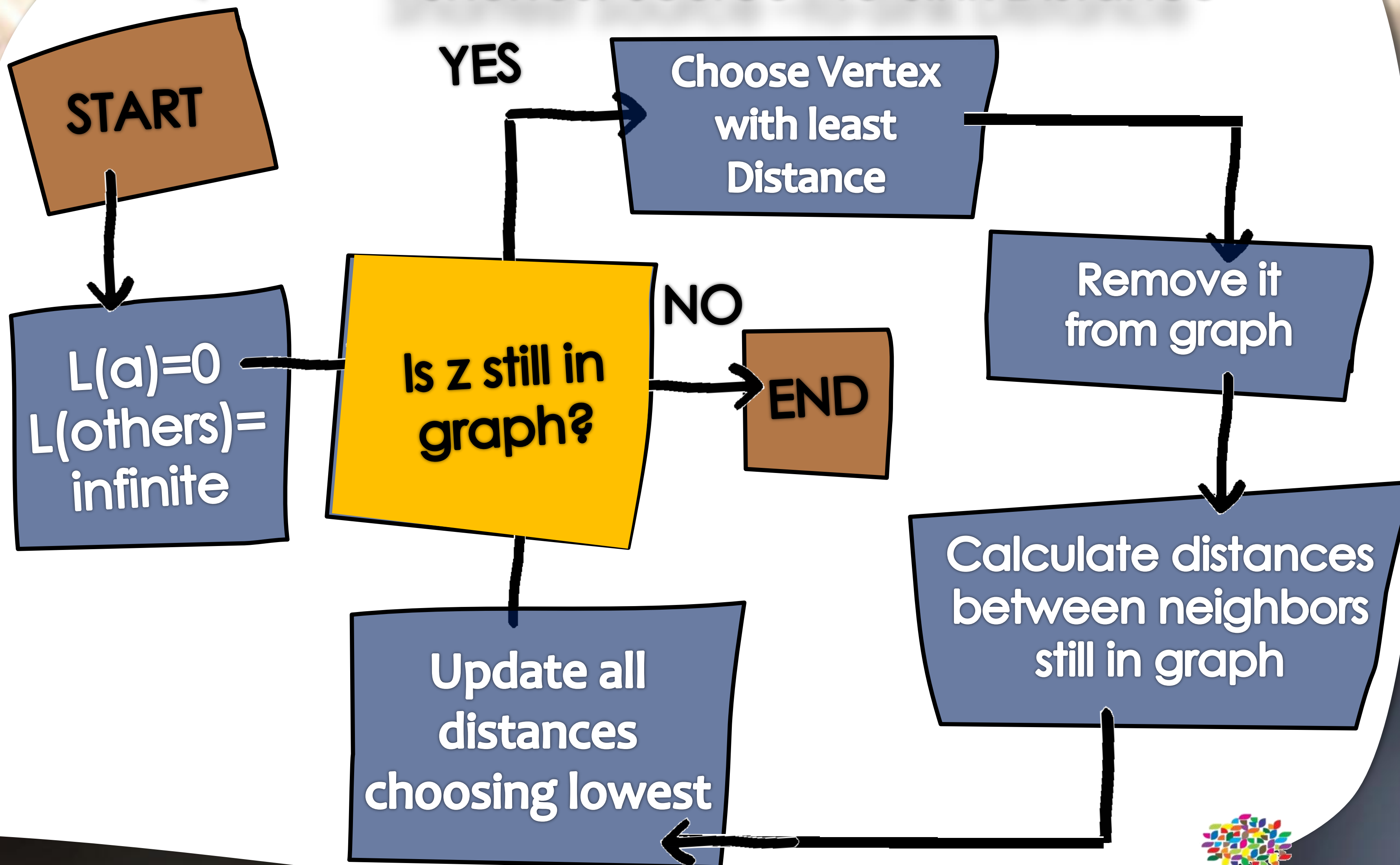
Alnouri S., Linke P., El. Halwagi M.M, 2014, Water Integration in Industrial Zones – A Spatial Representation with Direct Recycle Applications, Clean Techn Environ Policy, DOI 10.1007/s10098-014-0739

SPATIAL FRAMEWORK

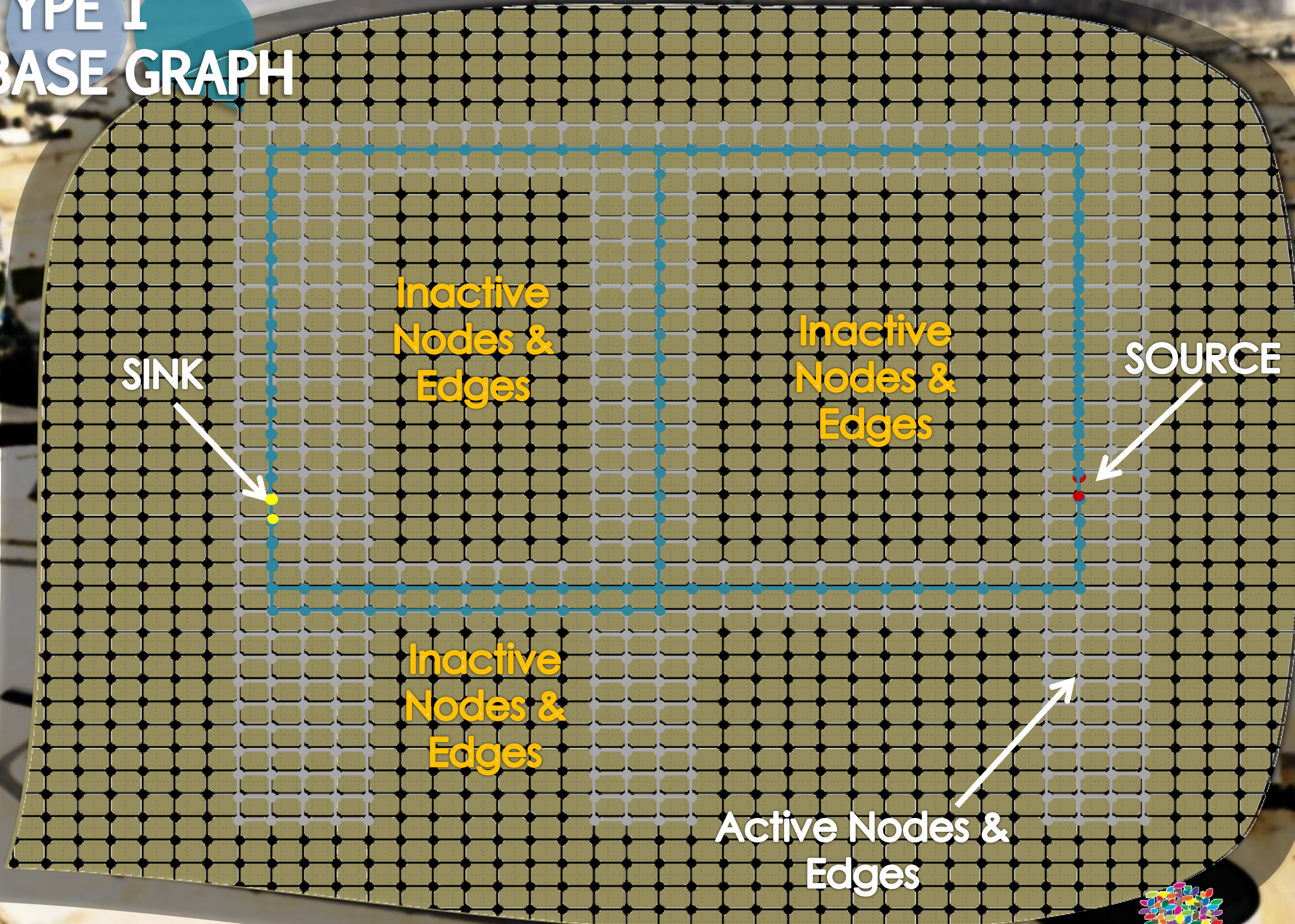


Alnouri S., Linke P., El. Halwagi M.M, 2014, Water Integration in Industrial Zones – A Spatial Representation with Direct Recycle Applications, Clean Techn Environ Policy, DOI 10.1007/s10098-014-0739

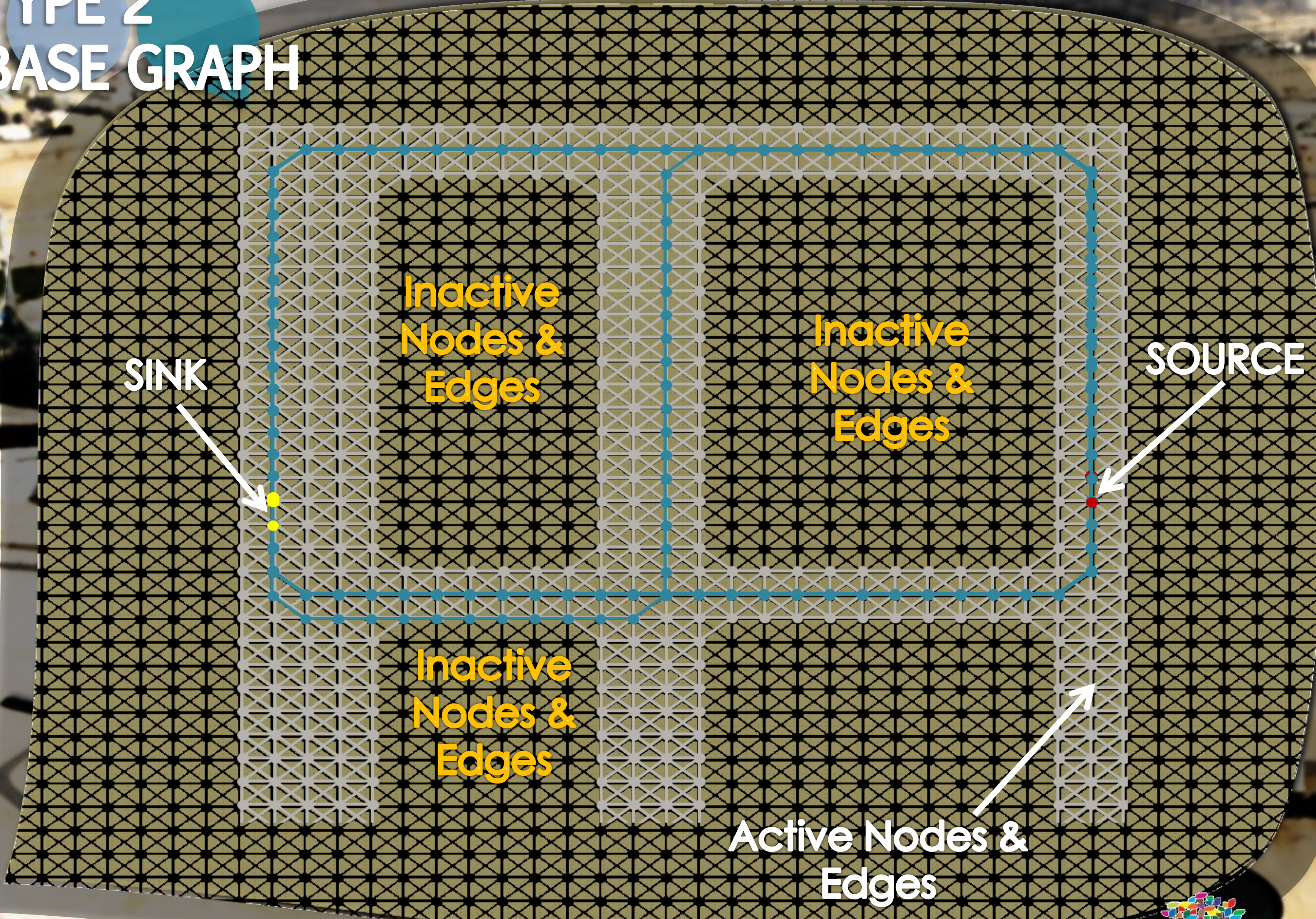
Dijkistra's Algorithm: Used to Extract Shortest Source –to-Sink Distance



TYPE 1
BASE GRAPH

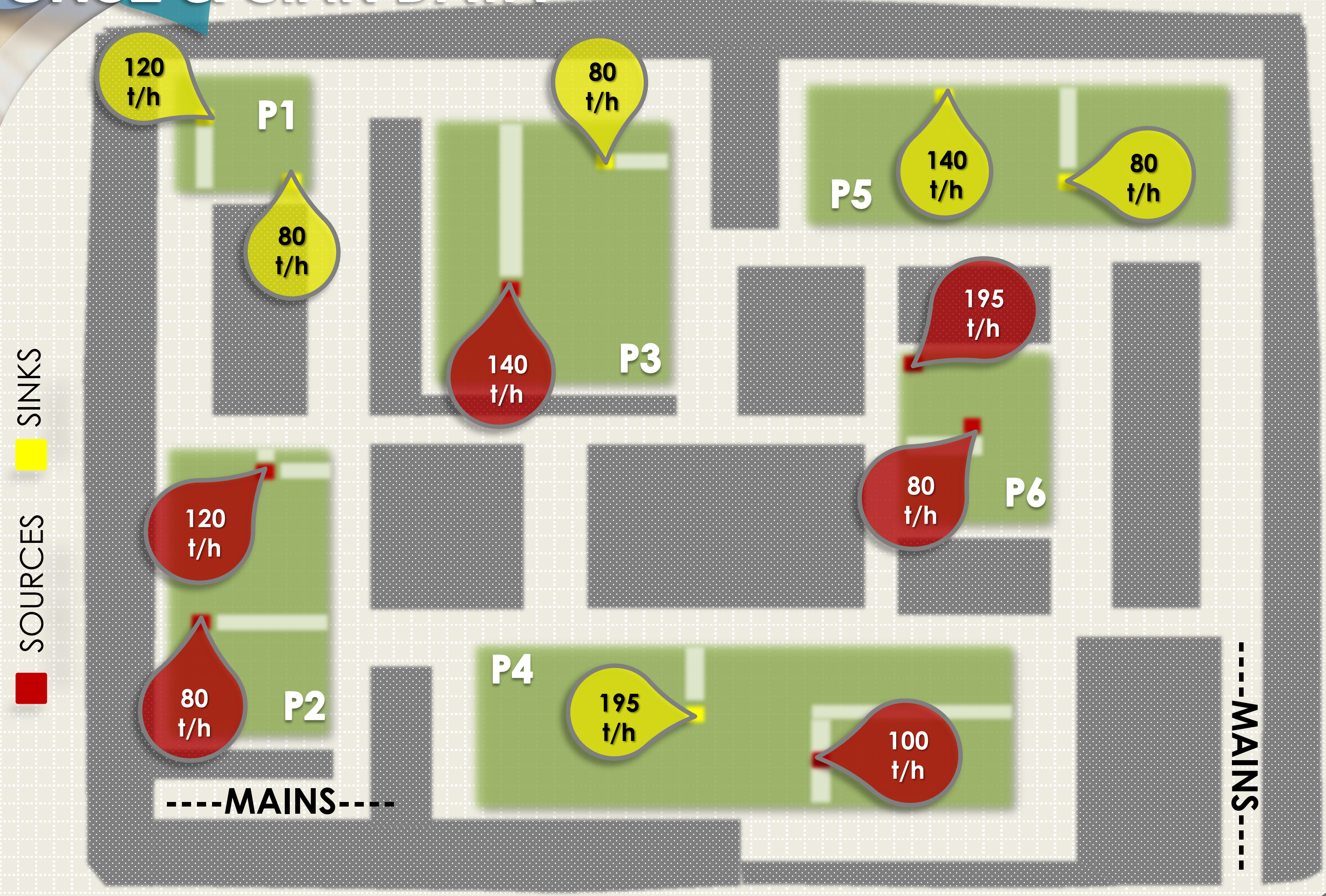


TYPE 2 BASE GRAPH



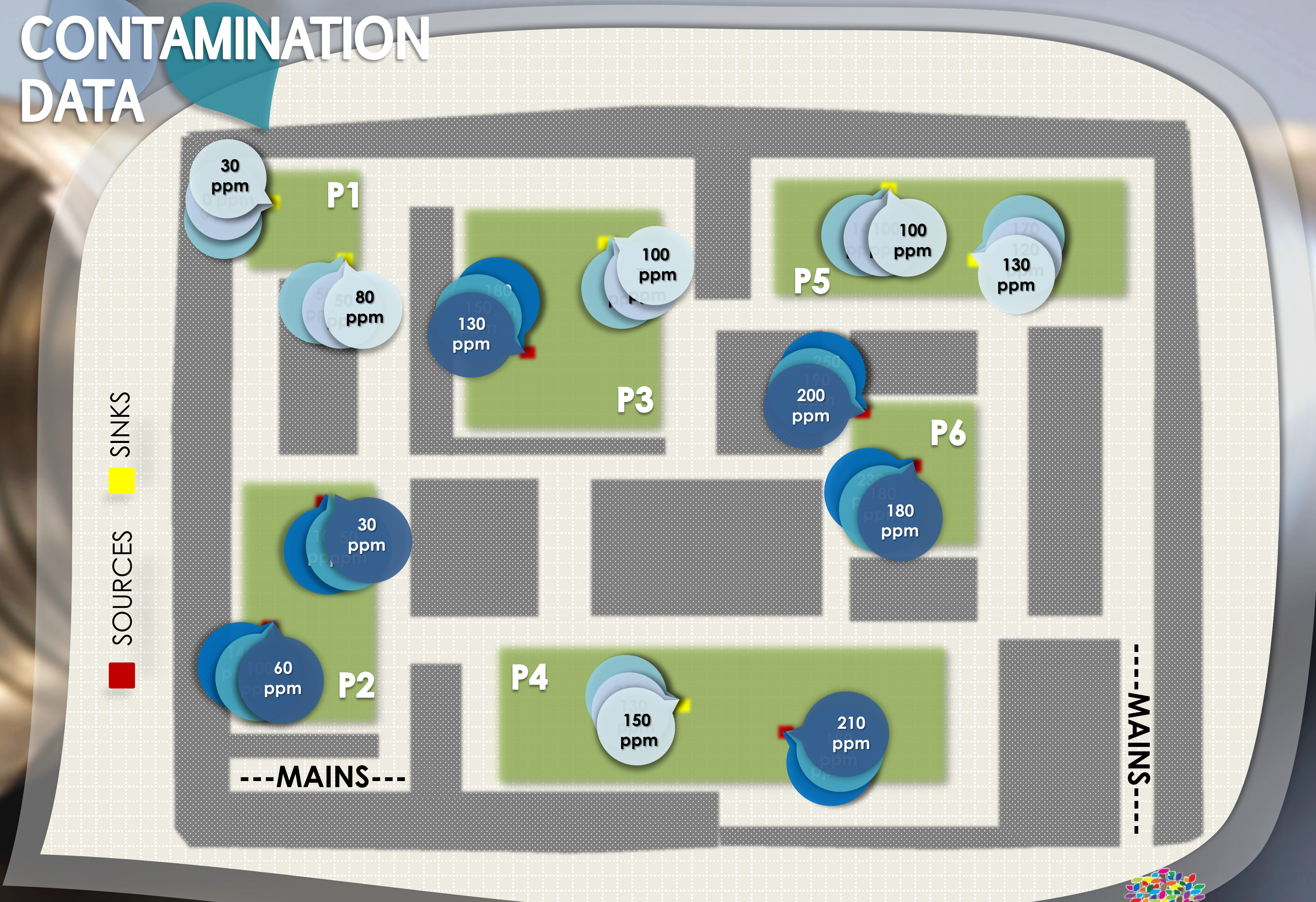
ILLUSTRATIVE CASE EXAMPLE

INDUSTRIAL CITY LAYOUT
SOURCE & SINK DATA

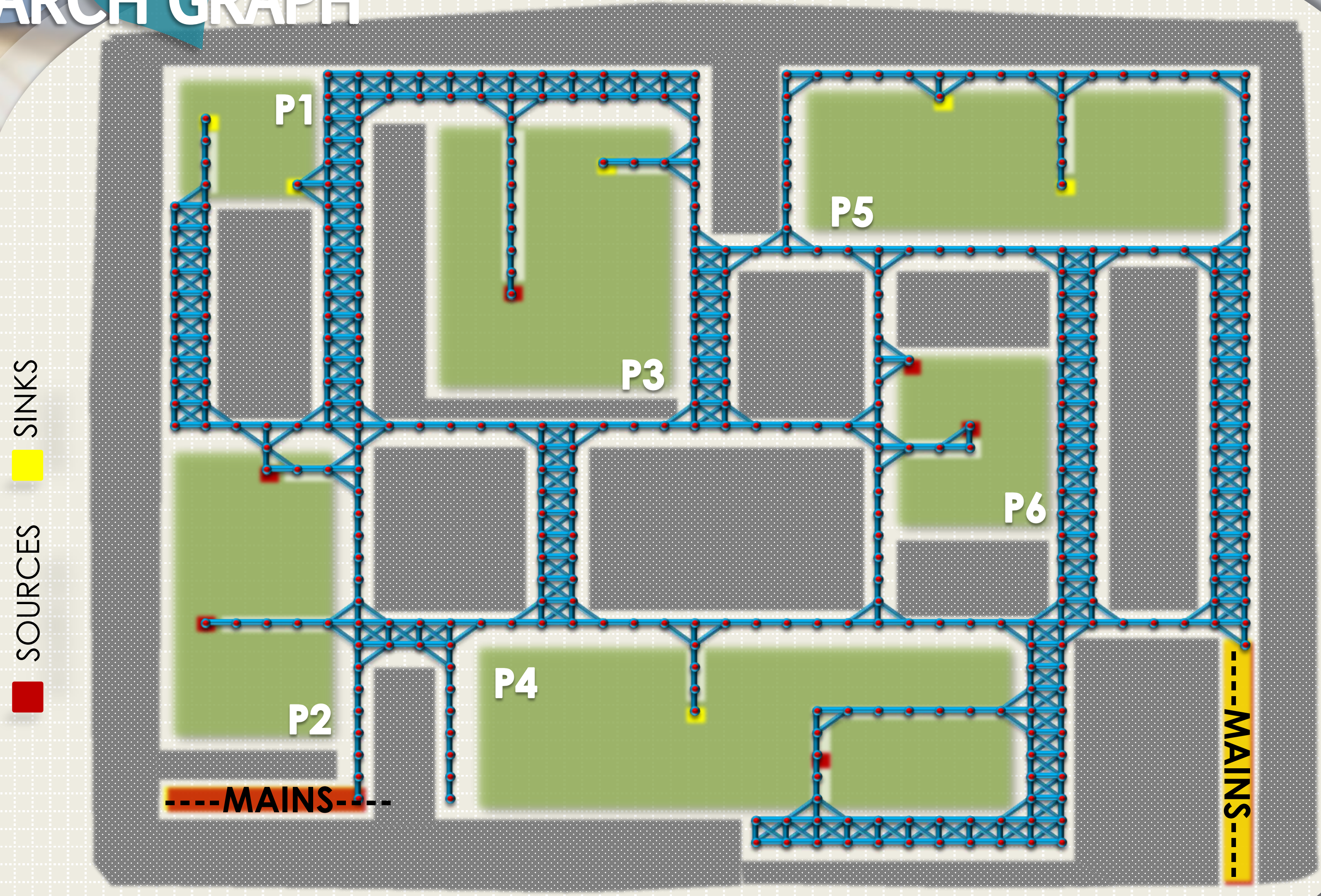


Given source/sink water flowrate data in each plant

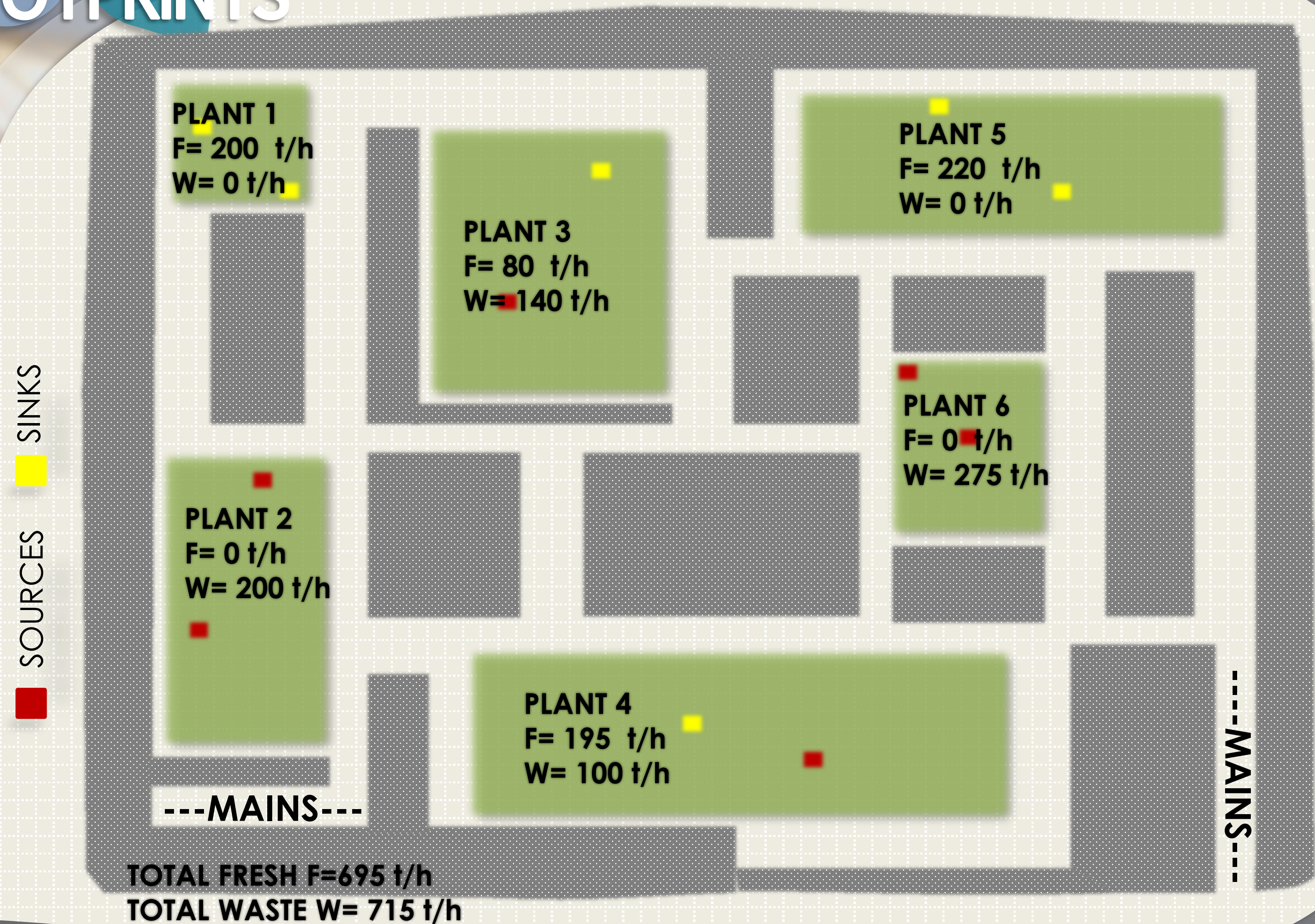
CONTAMINATION DATA



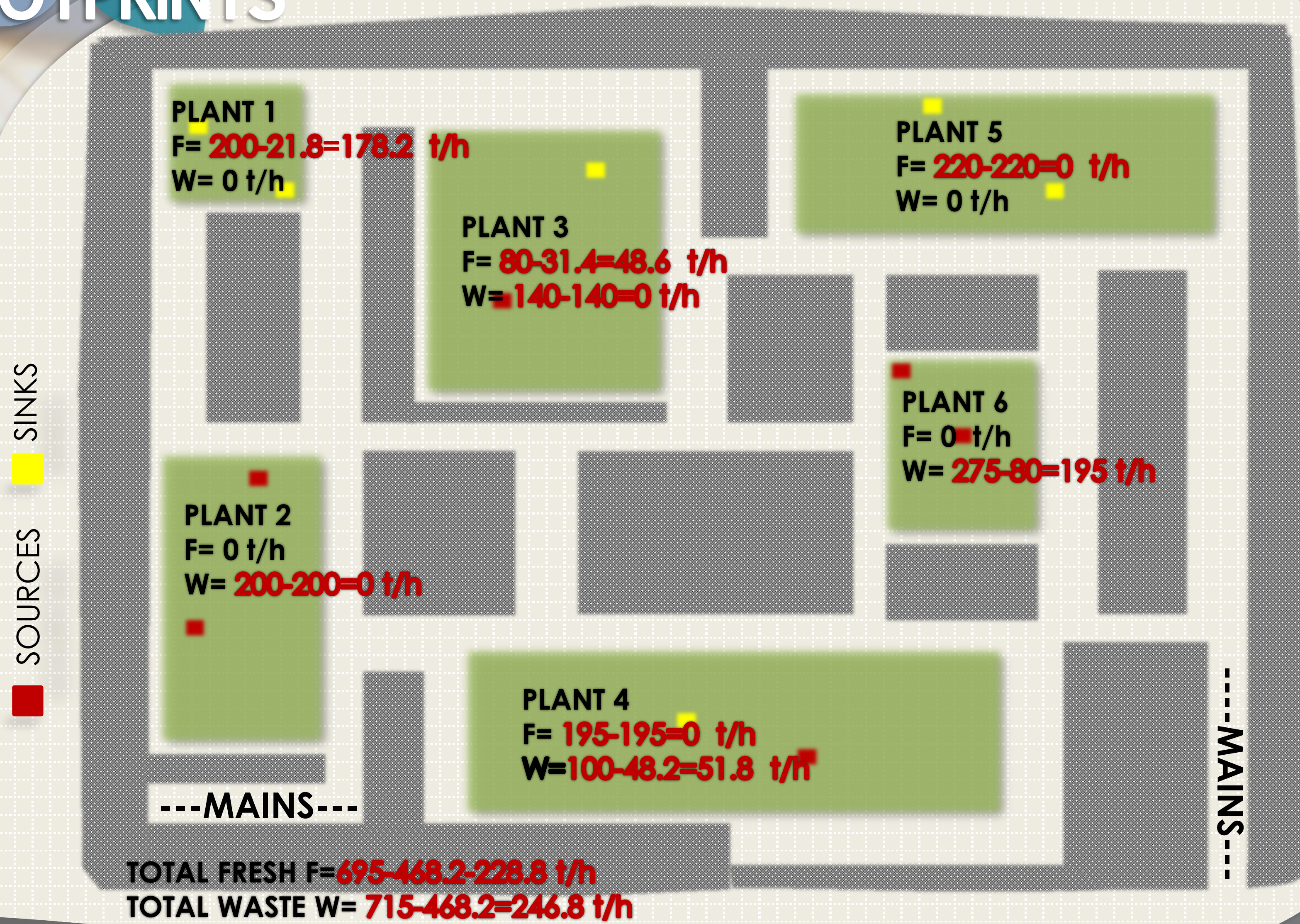
CONNECTIVITY SEARCH GRAPH



FRESH & WASTE FOOTPRINTS



FRESH & WASTE FOOTPRINTS



More Details

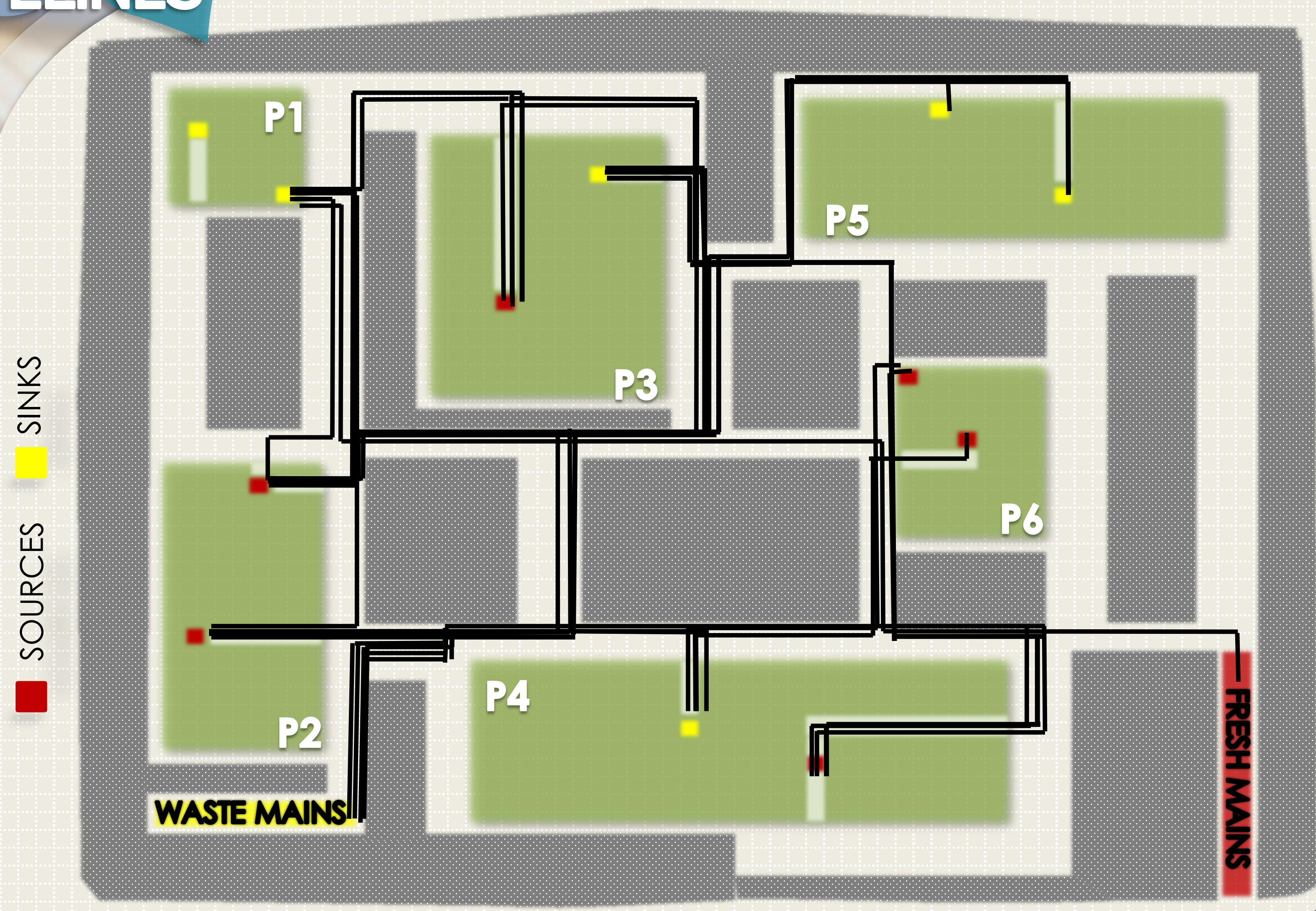
Clean Technologies and Environmental Policy
December 2014, Volume 16, Issue 8, pp 1637-1659

Date: 19 Mar 2014

Water integration in industrial zones: a spatial representation with direct recycle applications

Sabla Y. Alnouri, Patrick Linke, Mahmoud El-Halwagi

MULTIPLE PIPELINES



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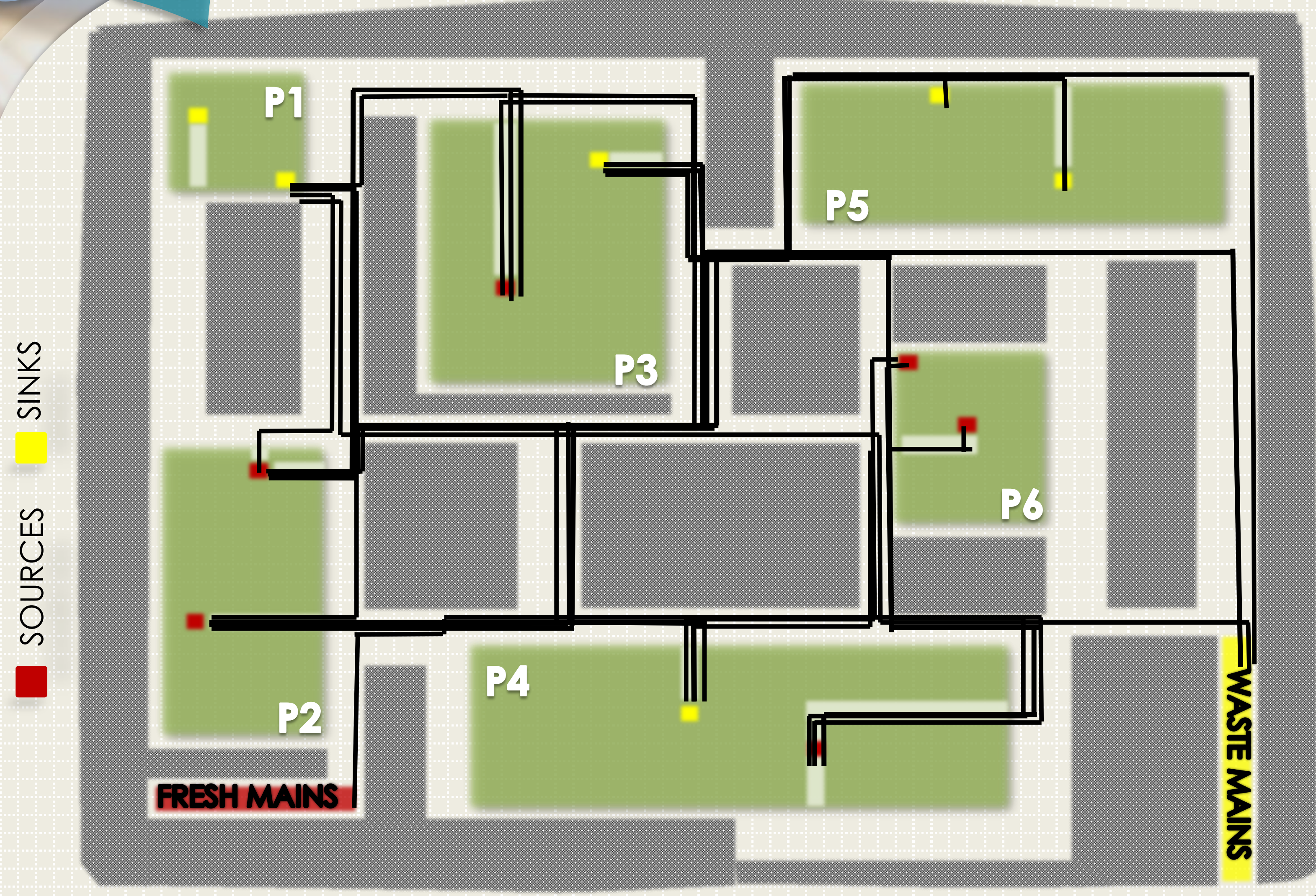
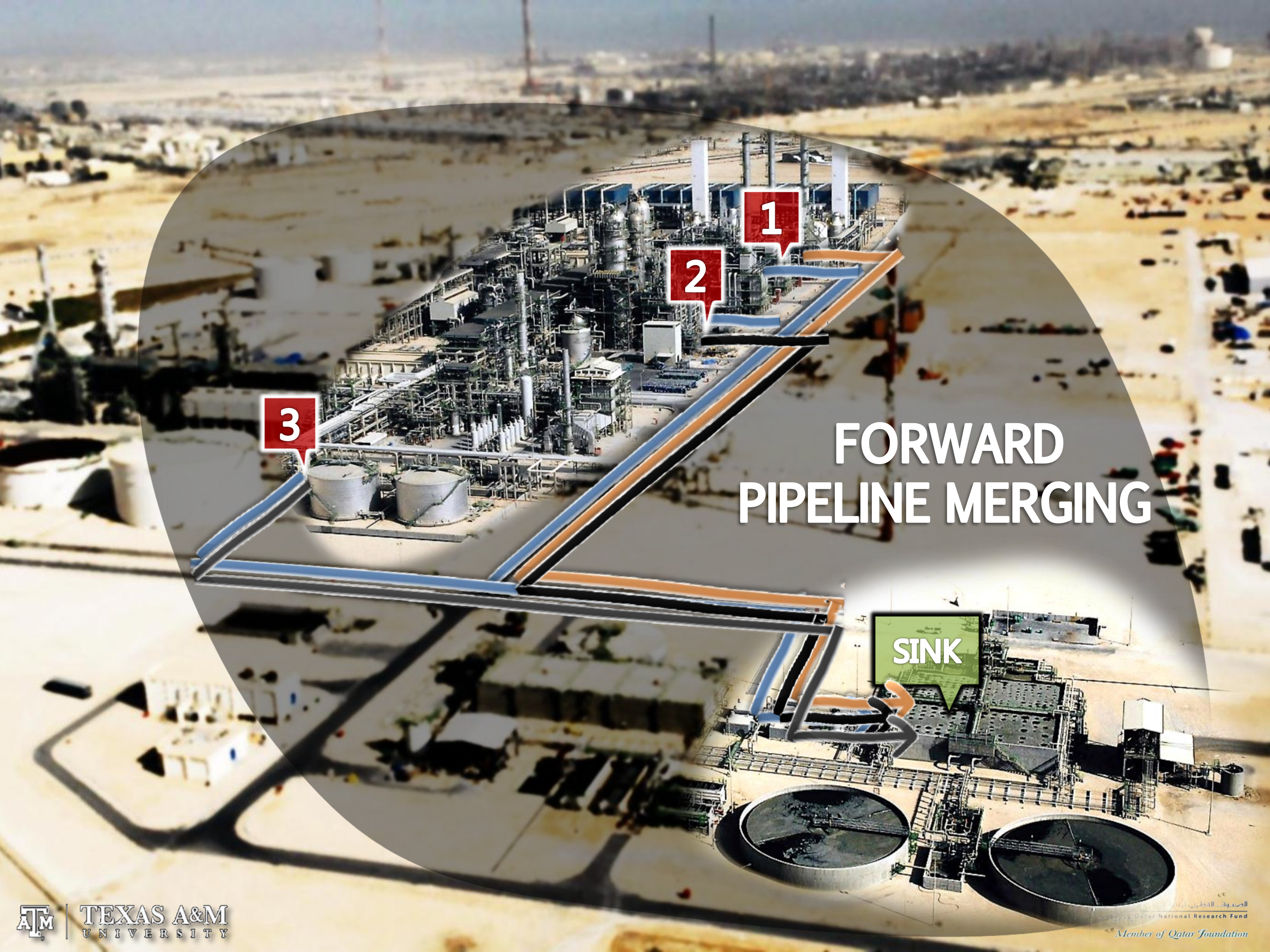
MULTIPLE PIPELINES



ADDRESSING PIPELINE INTERCONNECTIVITY

FORWARD PIPELINE MERGING

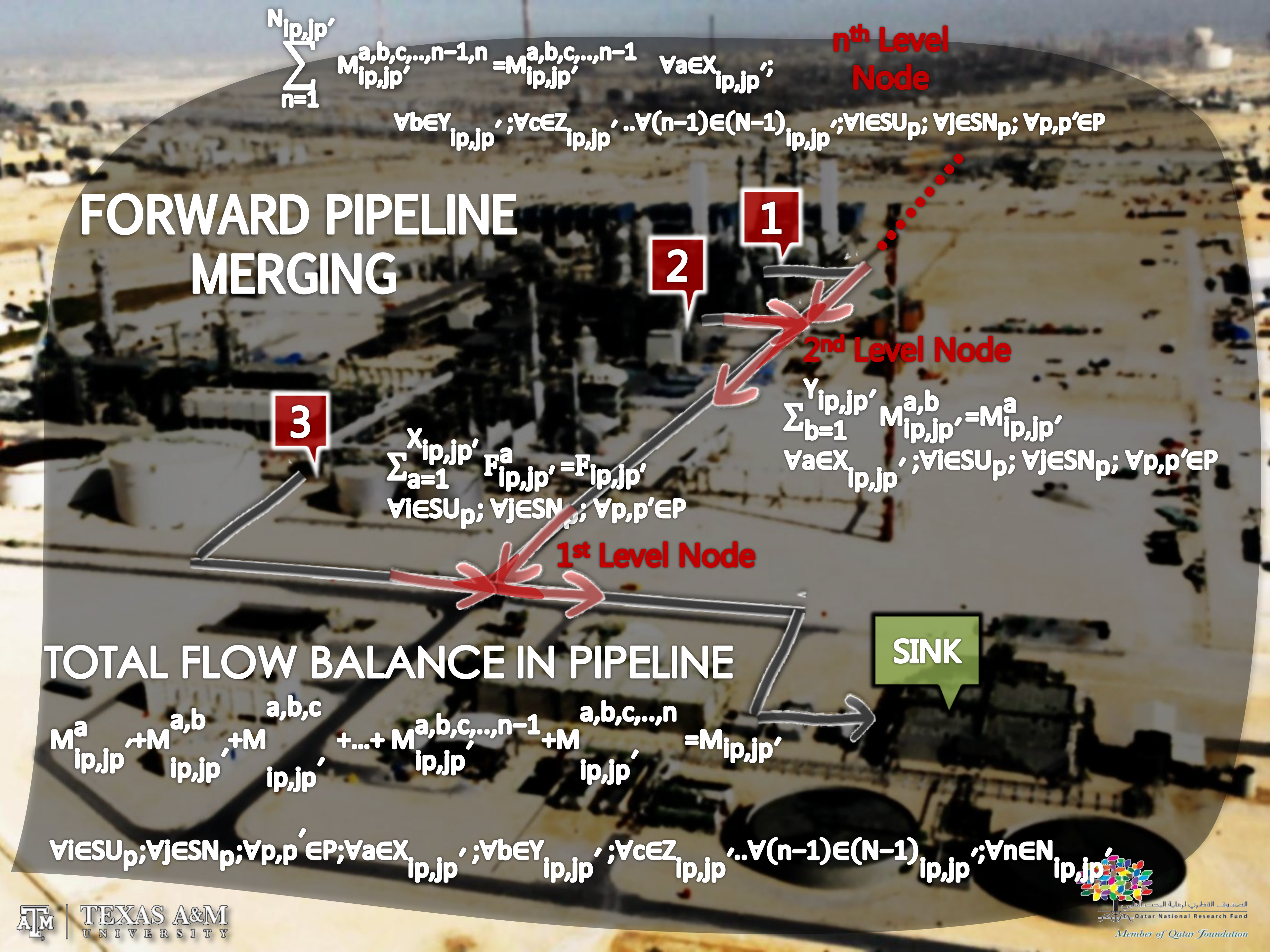


FORWARD PIPELINE MERGING

$$\sum_{n=1}^{N_{ip,jp'}} M_{ip,jp'}^{a,b,c,..,n-1,n} = M_{ip,jp'}^{a,b,c,..,n-1} \quad \forall a \in X_{ip,jp'};$$
$$\forall b \in Y_{ip,jp'}; \forall c \in Z_{ip,jp'} .. \forall (n-1) \in (N-1)_{ip,jp'}; \forall i \in SU_p; \forall j \in SN_p; \forall p,p' \in P$$

$$\sum_{b=1}^{Y_{ip,jp'}} M_{ip,jp'}^{a,b} = M_{ip,jp'}^{a}$$
$$\forall a \in X_{ip,jp'}; \forall i \in SU_p; \forall j \in SN_p; \forall p,p' \in P$$

$$\sum_{a=1}^{X_{ip,jp'}} F_{ip,jp'}^{a} = F_{ip,jp'}$$
$$\forall i \in SU_p; \forall j \in SN_p; \forall p,p' \in P$$



TOTAL FLOW BALANCE IN PIPELINE

$$M_{ip,jp'}^{a} + M_{ip,jp'}^{a,b} + M_{ip,jp'}^{a,b,c} + \dots + M_{ip,jp'}^{a,b,c,..,n-1} + M_{ip,jp'}^{a,b,c,..,n} = M_{ip,jp'}$$

$$\forall i \in SU_p; \forall j \in SN_p; \forall p,p' \in P; \forall a \in X_{ip,jp'}; \forall b \in Y_{ip,jp'}; \forall c \in Z_{ip,jp'} .. \forall (n-1) \in (N-1)_{ip,jp'}; \forall n \in N_{ip,jp'}$$

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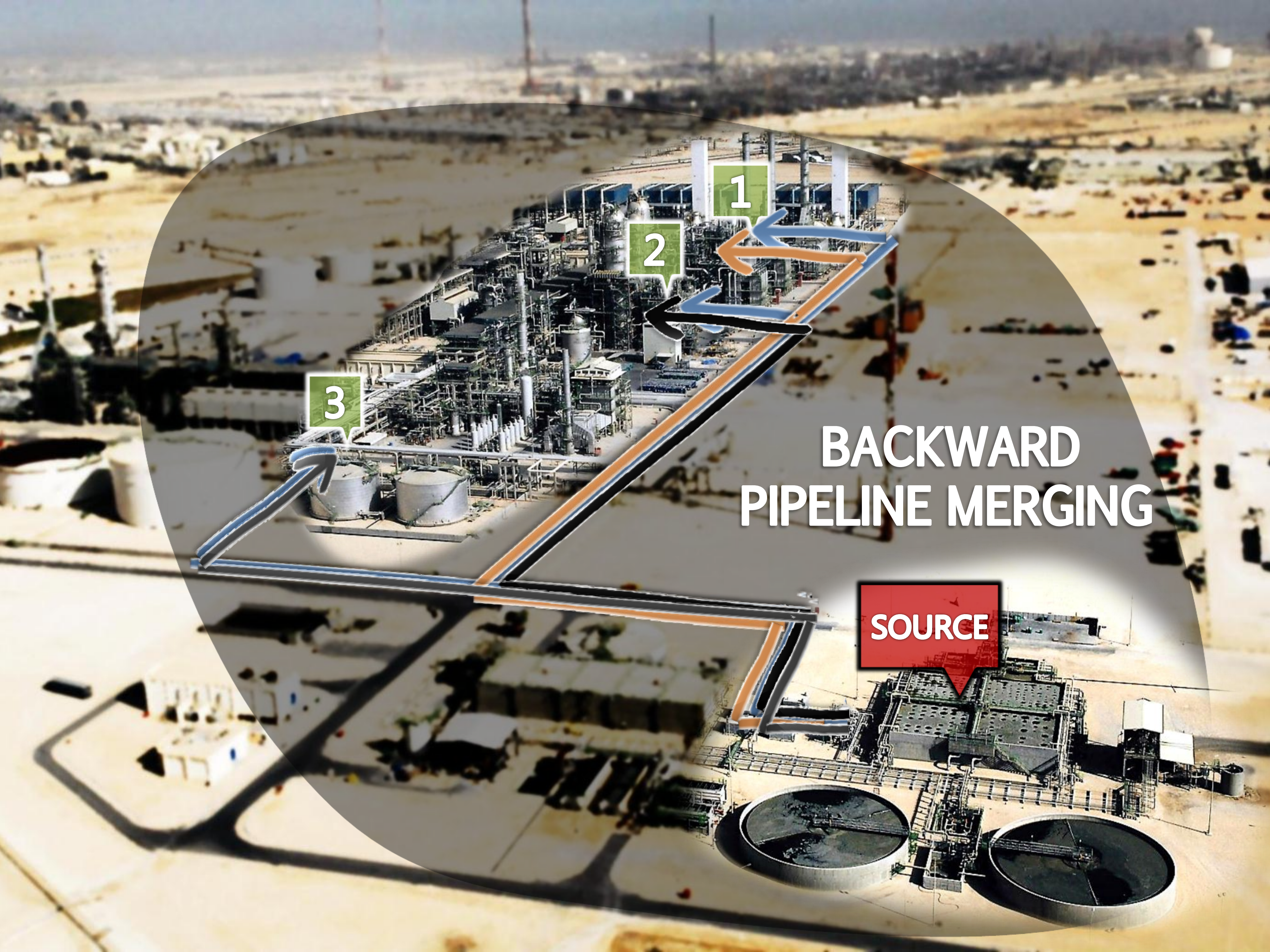
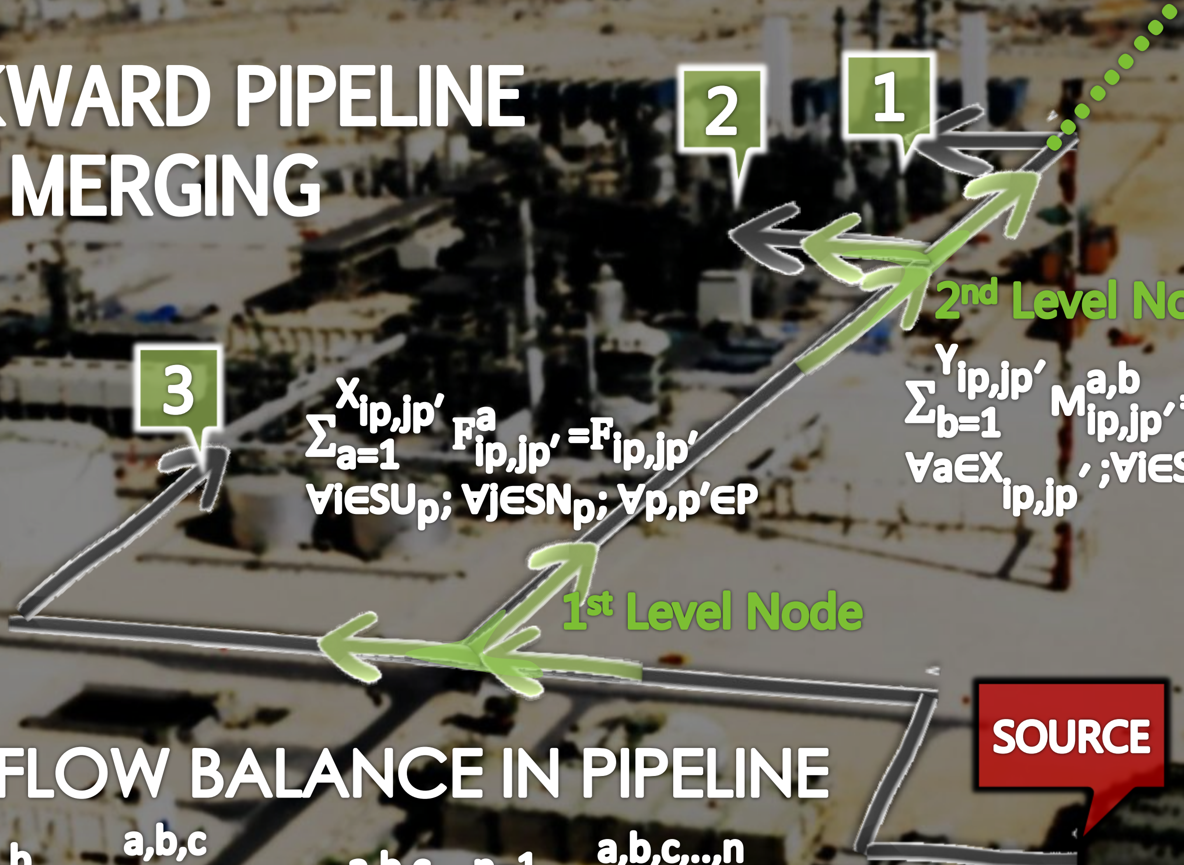

1
2
3
BACKWARD
PIPELINE MERGING
SOURCE

BACKWARD PIPELINE MERGING



$$\sum_{n=1}^{N_{ip,jp'}} M_{ip,jp'}^{a,b,c,..,n-1,n} = M_{ip,jp'}^{a,b,c,..,n-1} \quad \forall a \in X_{ip,jp'};$$

$$\forall b \in Y_{ip,jp'}; \forall c \in Z_{ip,jp'} .. \forall (n-1) \in (N-1)_{ip,jp'}; \forall i \in SU_p; \forall j \in SN_p; \forall p,p' \in P$$

$$\sum_{b=1}^{Y_{ip,jp'}} M_{ip,jp'}^{a,b} = M_{ip,jp'}^{a}$$

$$\forall a \in X_{ip,jp'}; \forall i \in SU_p; \forall j \in SN_p; \forall p,p' \in P$$

$$\sum_{a=1}^{X_{ip,jp'}} F_{ip,jp'}^{a} = F_{ip,jp'}$$

$$\forall i \in SU_p; \forall j \in SN_p; \forall p,p' \in P$$

TOTAL FLOW BALANCE IN PIPELINE

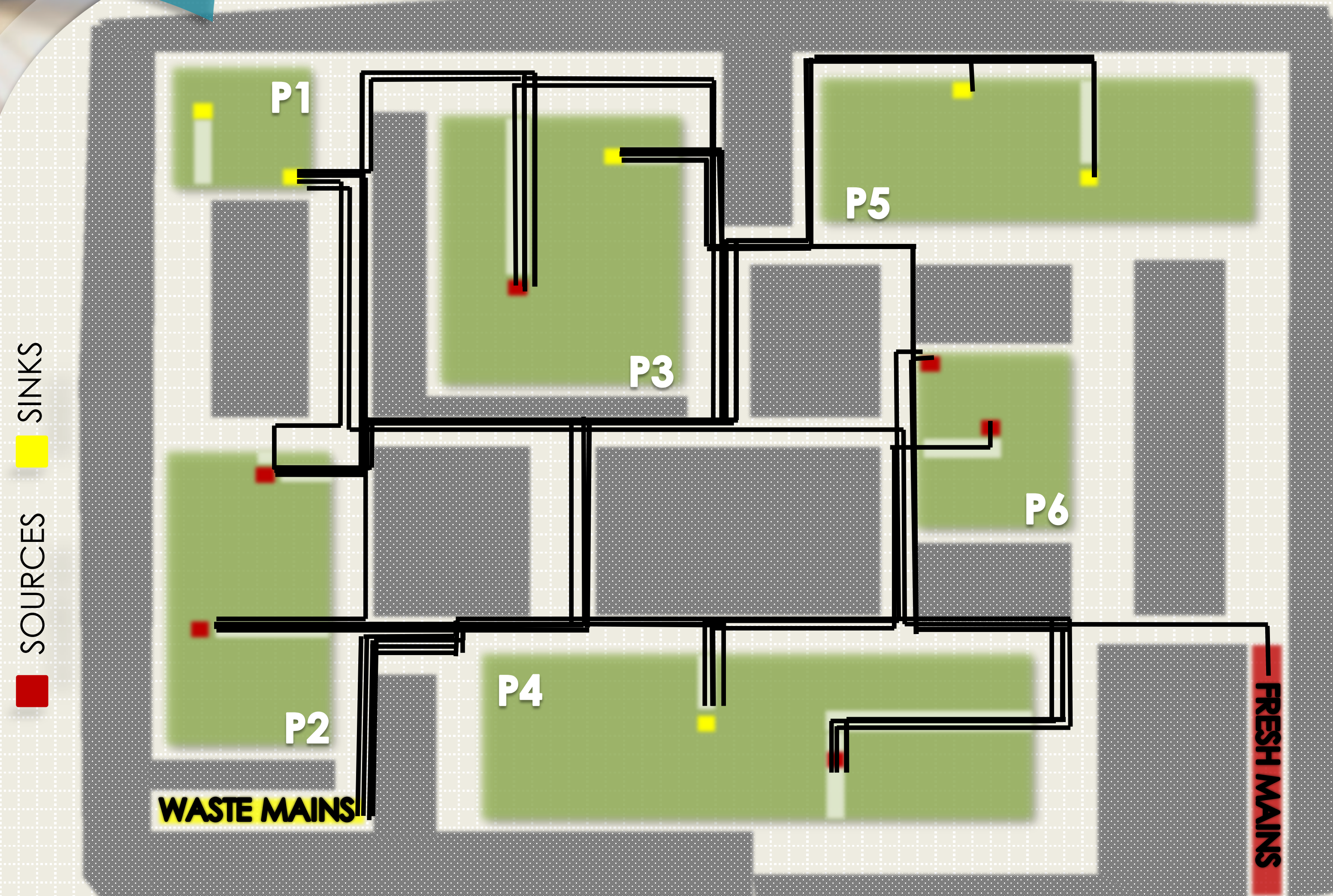
$$M_{ip,jp'}^{a} + M_{ip,jp'}^{a,b} + M_{ip,jp'}^{a,b,c} + \ldots + M_{ip,jp'}^{a,b,c,..,n-1} + M_{ip,jp'}^{a,b,c,..,n} = M_{ip,jp'}$$

$$\forall i \in SU_p; \forall j \in SN_p; \forall p,p' \in P; \forall a \in X_{ip,jp'}; \forall b \in Y_{ip,jp'}; \forall c \in Z_{ip,jp'} .. \forall (n-1) \in (N-1)_{ip,jp'}; \forall n \in N_{ip,jp'}$$

ILLUSTRATIVE CASE EXAMPLE

MULTIPLE PIPELINES

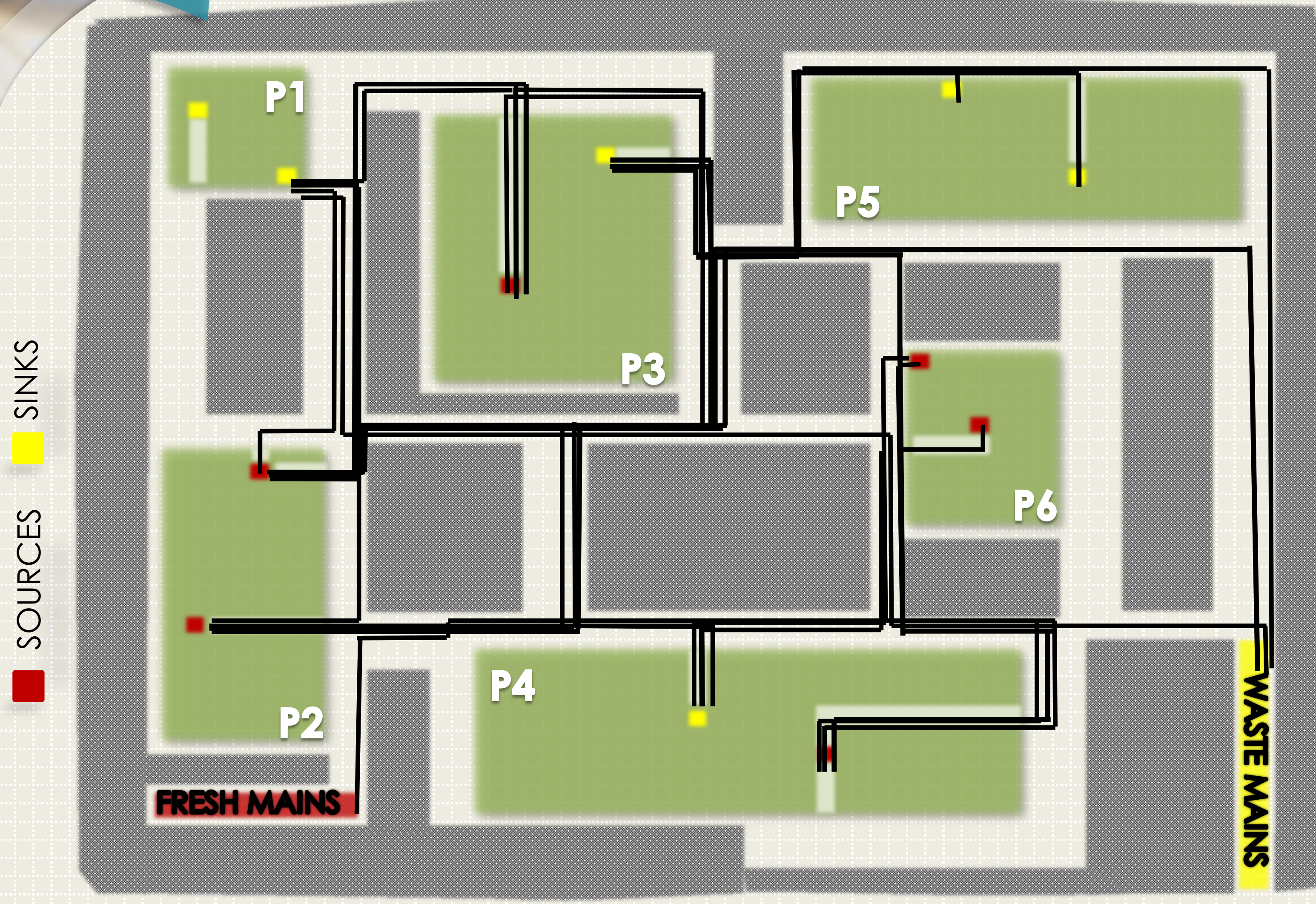
FORWARD BRANCHING ACHIEVED 4.2% SAVINGS



$12,763,003 --------------------------------$12,011,167
(BEFORE MERGING) (AFTER MERGING)

MULTIPLE PIPELINES

BACKWARD BRANCHING ACHIEVED 7.7% SAVINGS



$11,211,408 ----------------------------------$9,954,339
(BEFORE MERGING) (AFTER MERGING)

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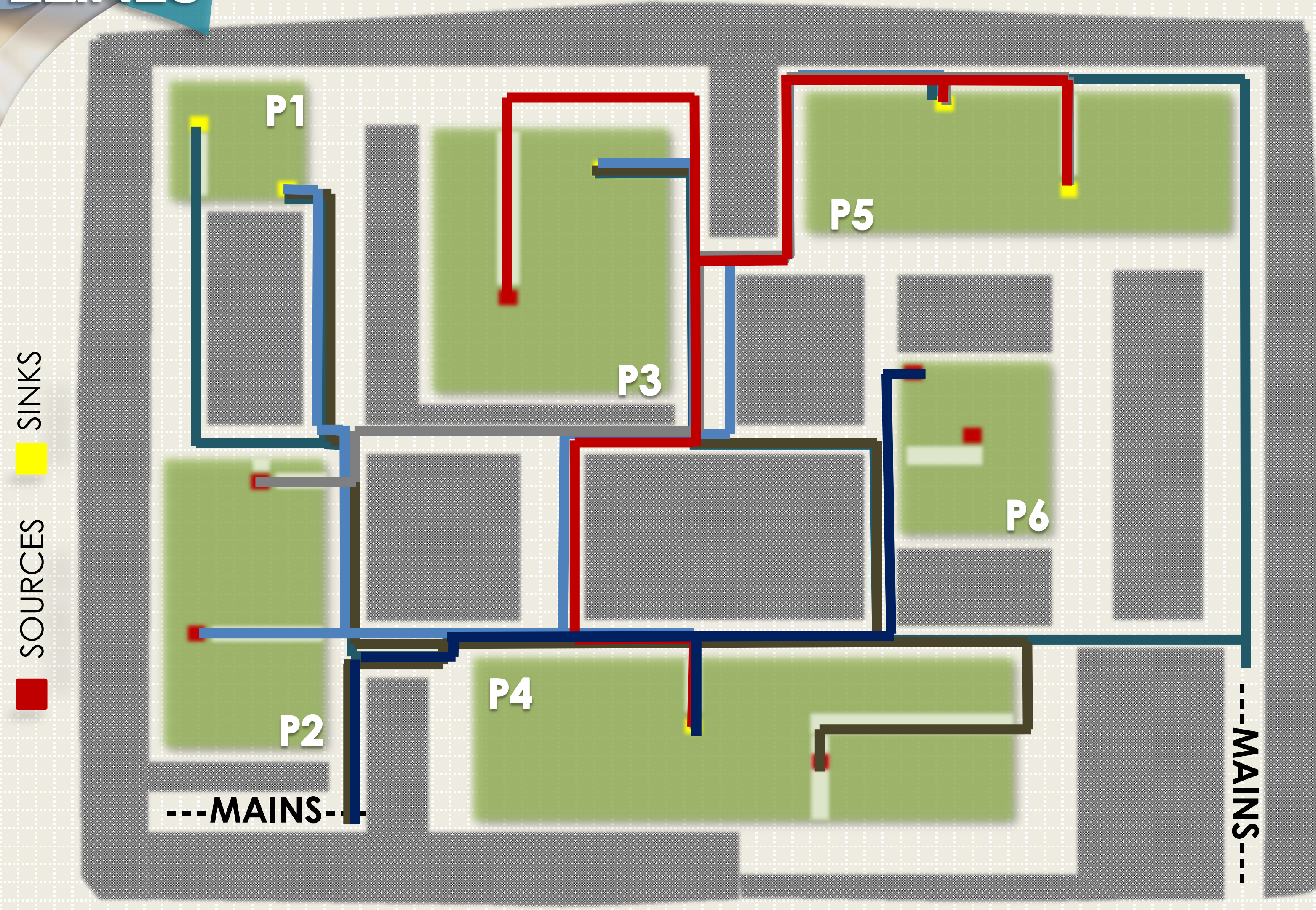
MERGED PIPELINES



More Details

AIChE JOURNAL

Process Systems Engineering

Optimal interplant water networks for industrial zones: Addressing interconnectivity options through pipeline merging

Sabla Y. Alnouri[1,2], Patrick Linke[1,*] and Mahmoud El-Halwagi[3]

Article first published online: 11 JUN 2014

DOI: 10.1002/aic.14516

Issue

AIChE Journal

Volume 60, Issue 8, pages 2853–2874, August 2014

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INTRODUCING CENTRALIZED & DECENTRALIZED TREATMENT OPTIONS

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WASTEWATER TREATMENT

PRE-TREATMENT

- Filtration
- Softening
- MF/UF
- Oil & Grease Removal
- Clarification
- Ion Exchange

VOLATILES REMOVAL

- Stripping
- Oxygen Removal
- De-carbonation

THERMAL & MEMBRANE

- Nanofiltration
- Membrane Distillation
- Reverse Osmosis
- Ultrafiltration
- Multiple Effect Distillation

POST-TREATMENT

- Remineralization
- Chlorination
- Oxidation
- Electrodeionization

WATER TREATMENT IN INDUSTRY

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WATER TREATMENT FACILITY
Water Consuming Operation
PROCESSING FACILITY
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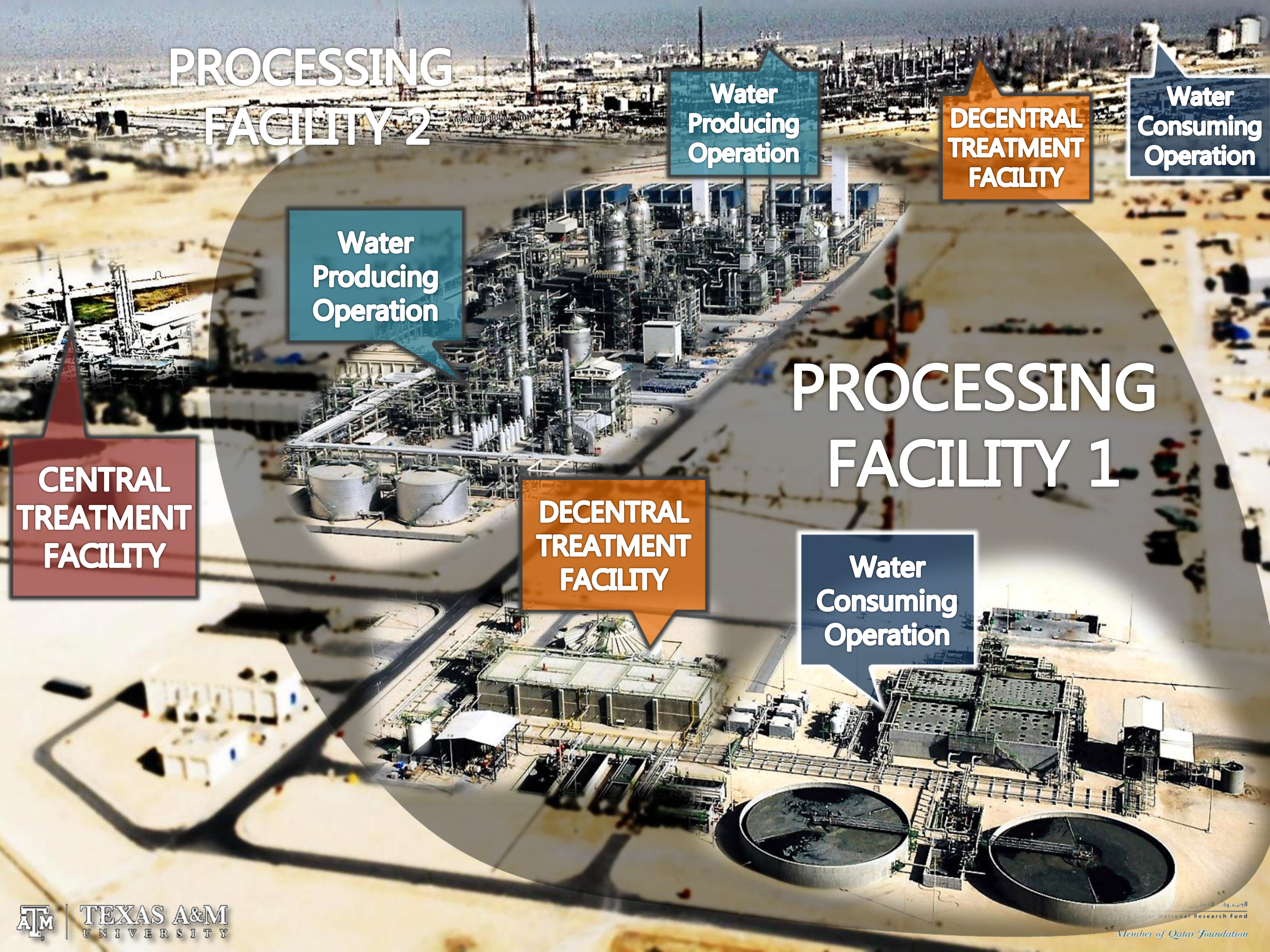
PROCESSING FACILITY 2
Water Producing Operation
DECENTRAL TREATMENT FACILITY
Water Consuming Operation
Water Producing Operation
CENTRAL TREATMENT FACILITY
PROCESSING FACILITY 1
DECENTRAL TREATMENT FACILITY
Water Consuming Operation
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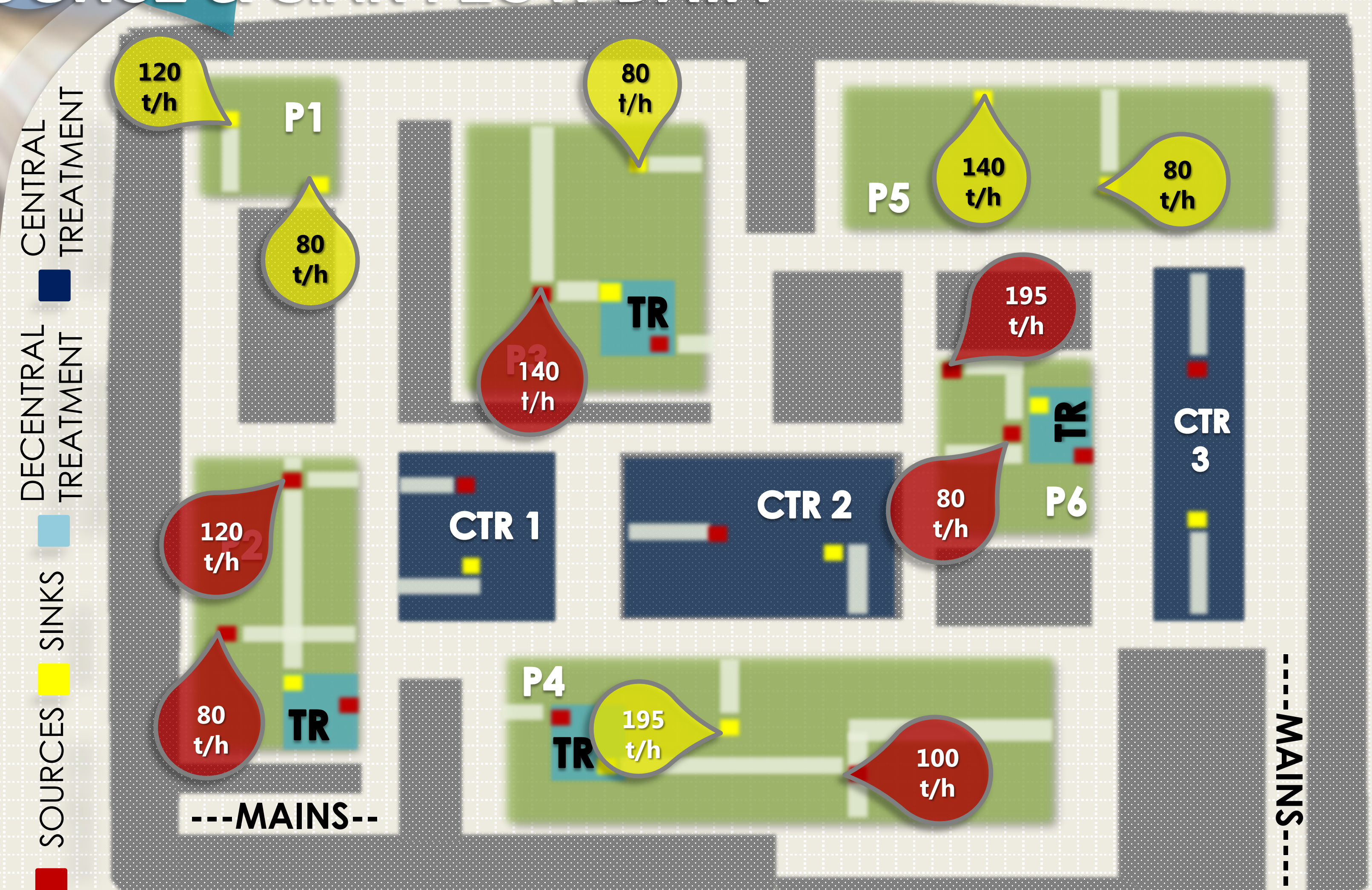
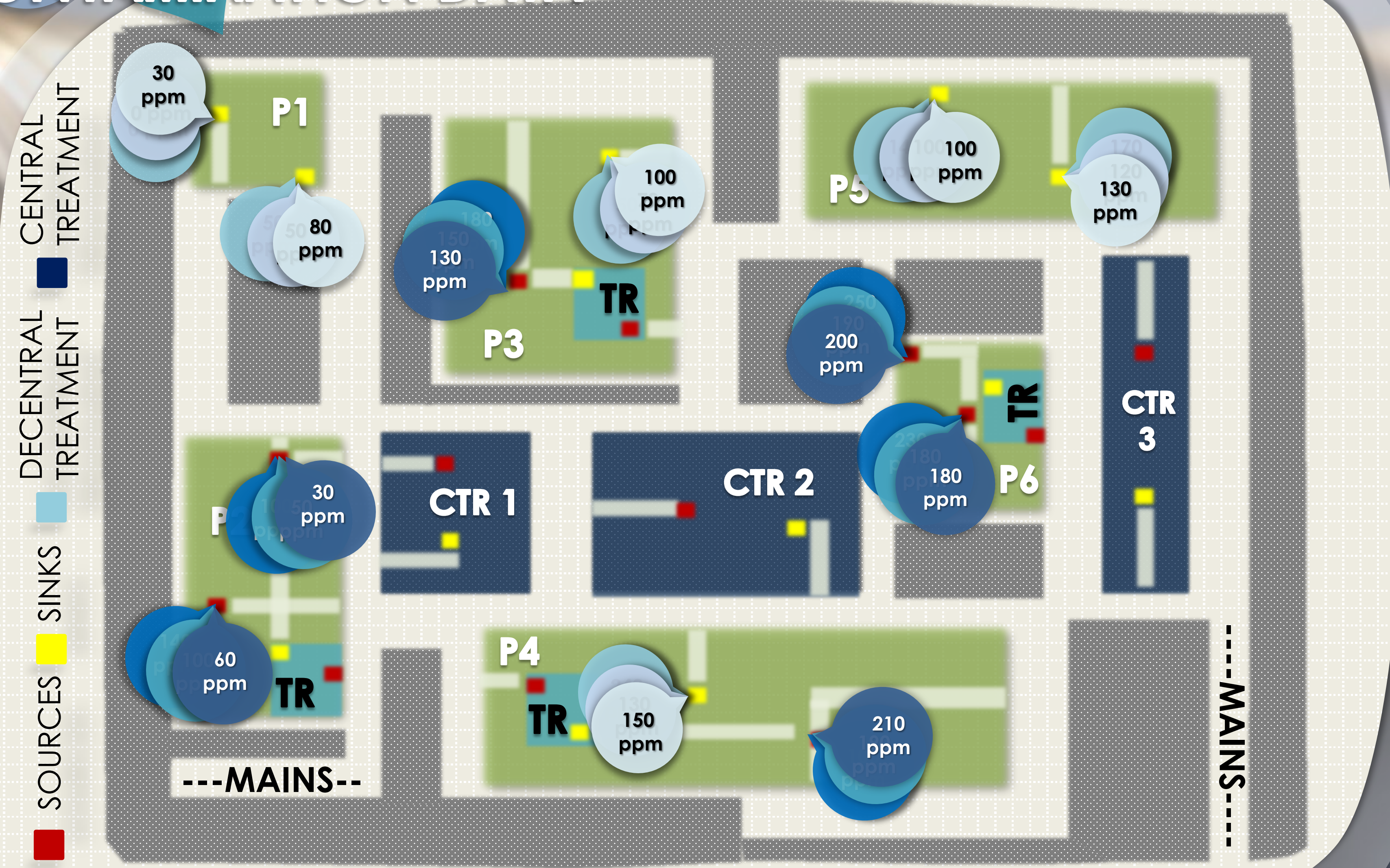
ILLUSTRATIVE CASE EXAMPLE

INDUSTRIAL CITY LAYOUT SOURCE & SINK FLOW DATA



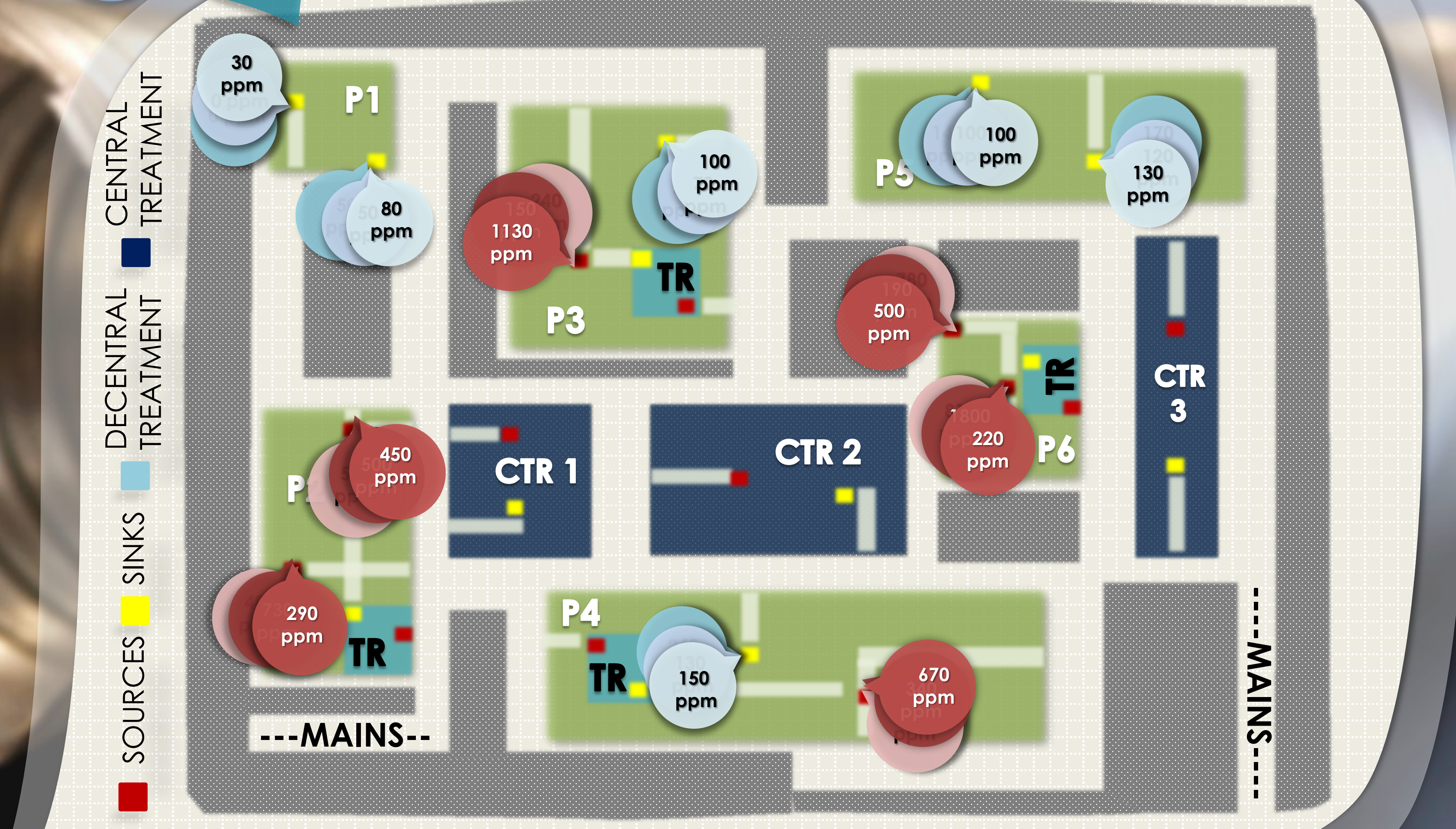
Given source/sink water flowrate data in each plant

SOURCE & SINK CONTAMINATION DATA



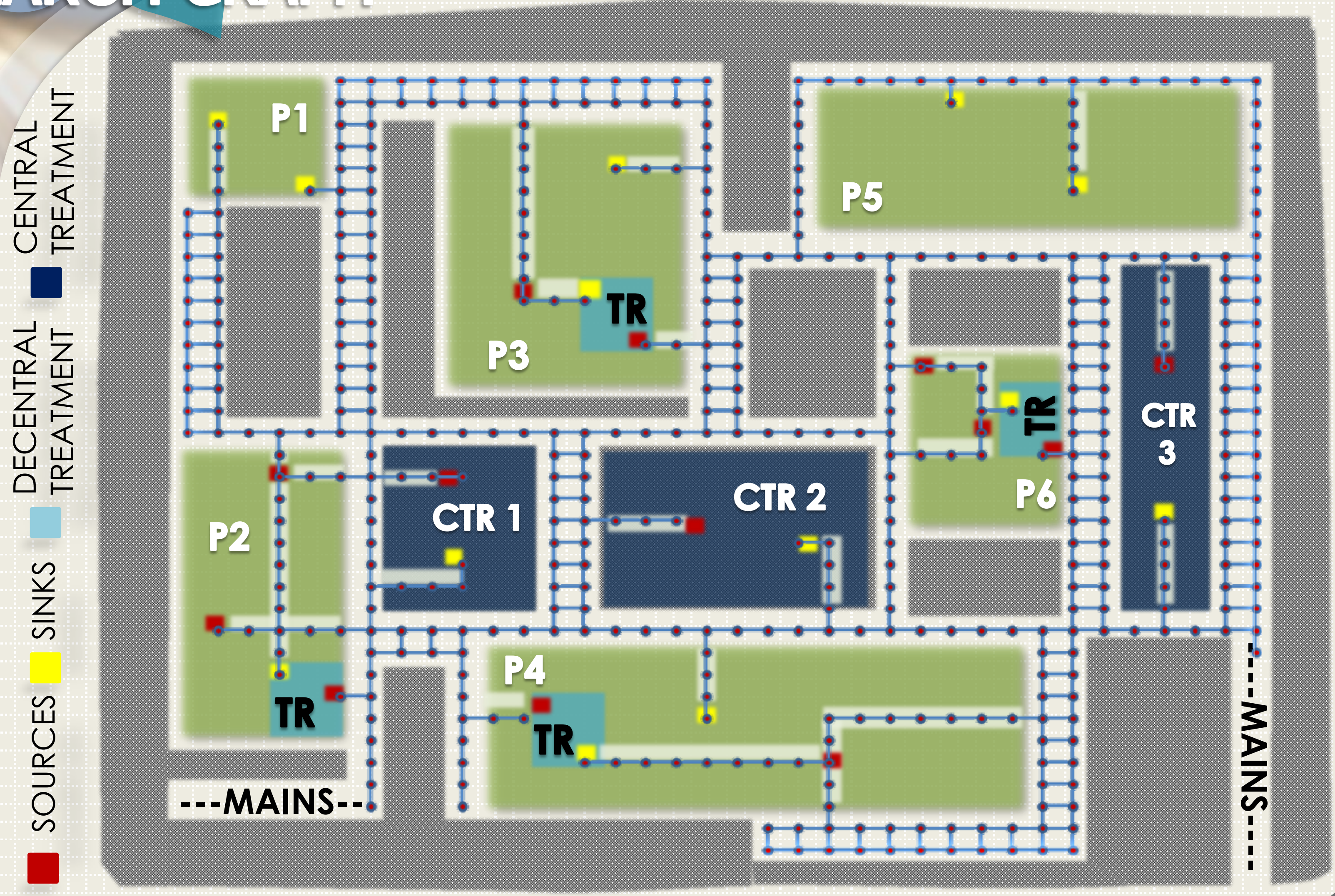
Given source/sink water contamination data in each plant

SOURCE & SINK CONTAMINATION DATA



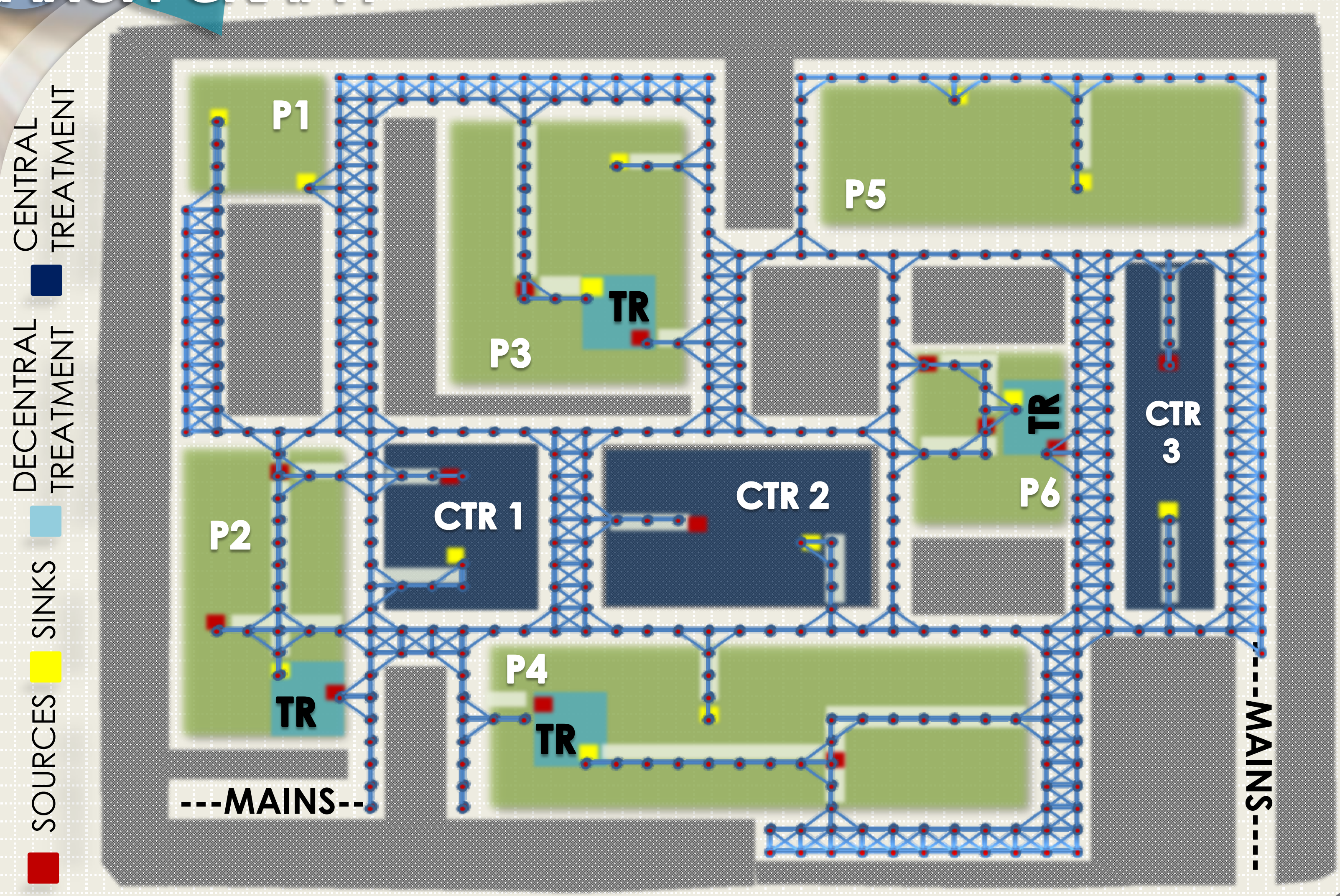
Given source/sink water contamination data in each plant

CONNECTIVIY SEARCH GRAPH



TYPE 1 CONNECTIVITY CONSTRAINTS

CONNECTIVIY SEARCH GRAPH



TYPE 2 CONNECTIVITY CONSTRAINTS

More Details

Journal of Cleaner Production 89 (2015) 231–250

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

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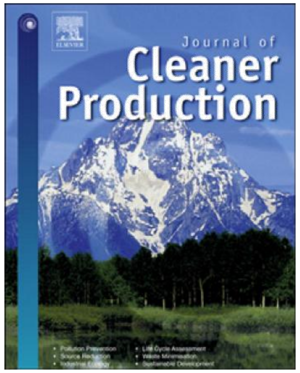

A synthesis approach for industrial city water reuse networks considering central and distributed treatment systems

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[b] The Artie McFerrin Department of Chemical Engineering, Texas A&M University, College Station, TX, USA

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MULTIPERIOD PLANNING

I&EC research
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Article

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Multiperiod Planning of Optimal Industrial City Direct Water Reuse Networks

Sumit Kr. Bishnu,[†] Patrick Linke,*[,†] Sabla Y. Alnouri,[†] and Mahmoud El-Halwagi[‡]

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[‡]The Artie McFerrin Department of Chemical Engineering, Texas A&M University, College Station, Texas 77843-3122, United States

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