Recycling and Reuse of Water Resources for the Arid and Water-Deficient Area in Western China

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1. Western China and its Present Conditions

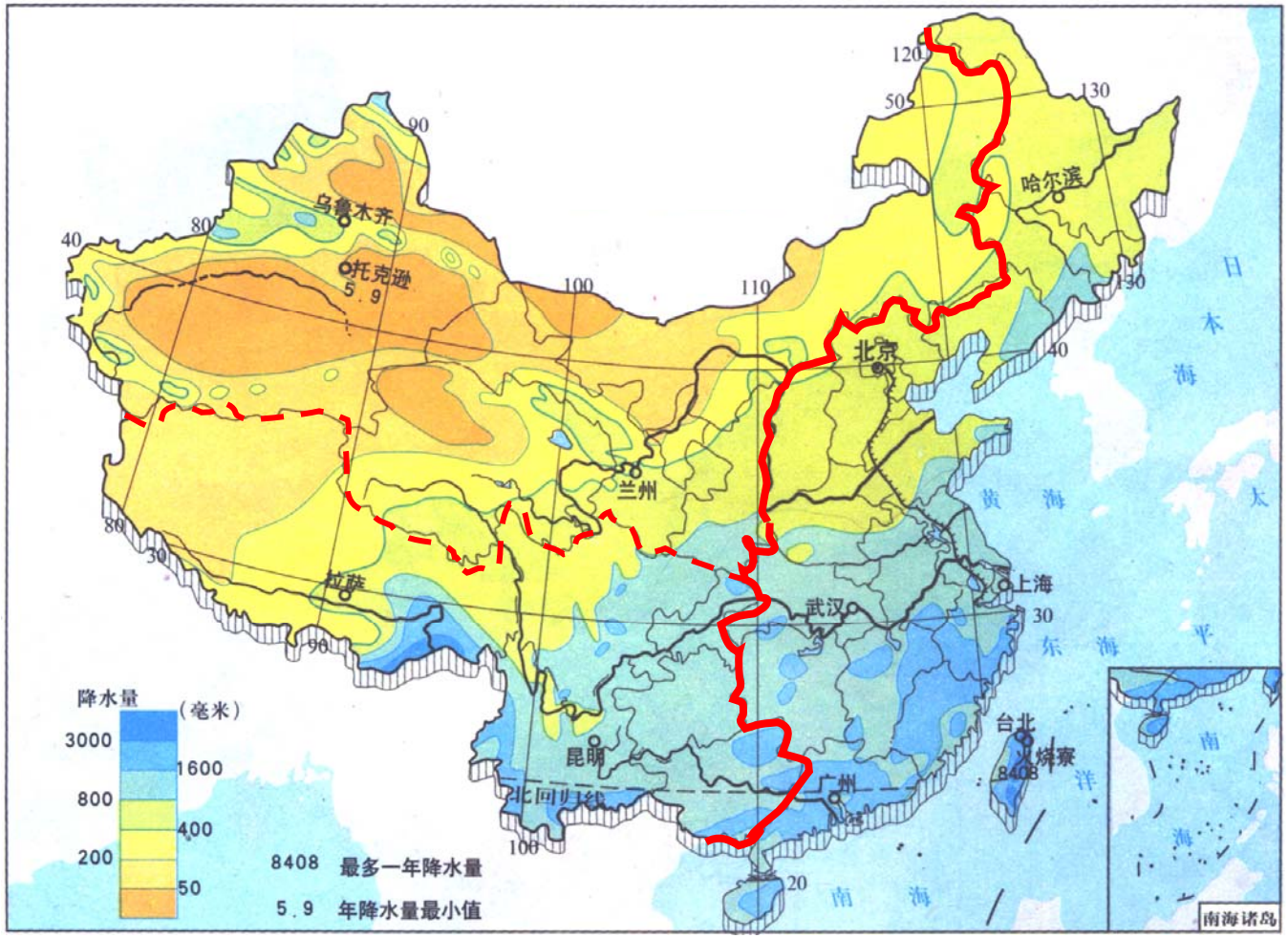
Location map of Western China

Basic data of Western China

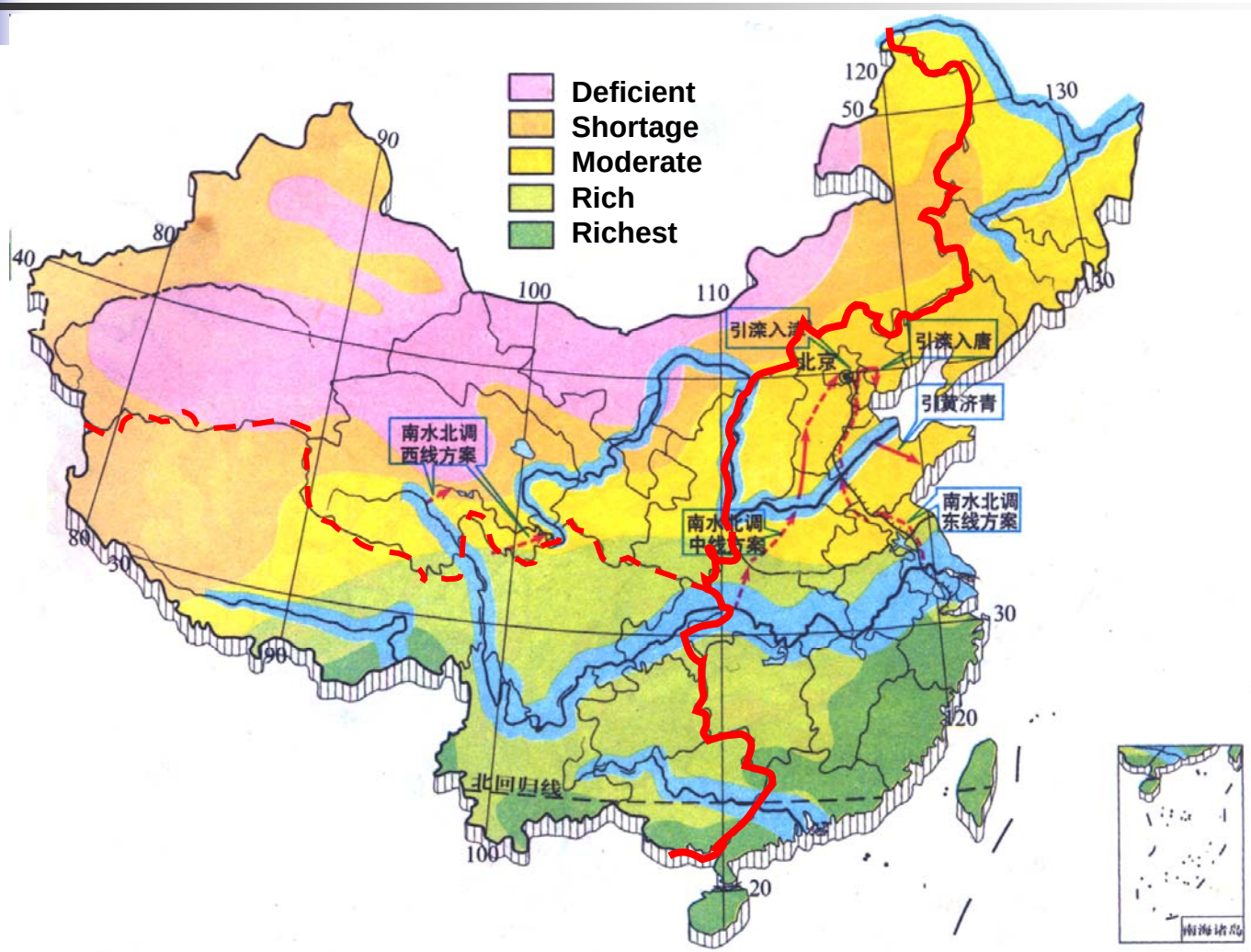
	Western	Whole Country
Area (' 000 km^2)	6,867	9,602
Population (million)	341	1,248
GDP (million RMB)	1,205,300	7,834,500
GDP per capita (US$)	3,535	6,278

Note: data based on 1998 statistics

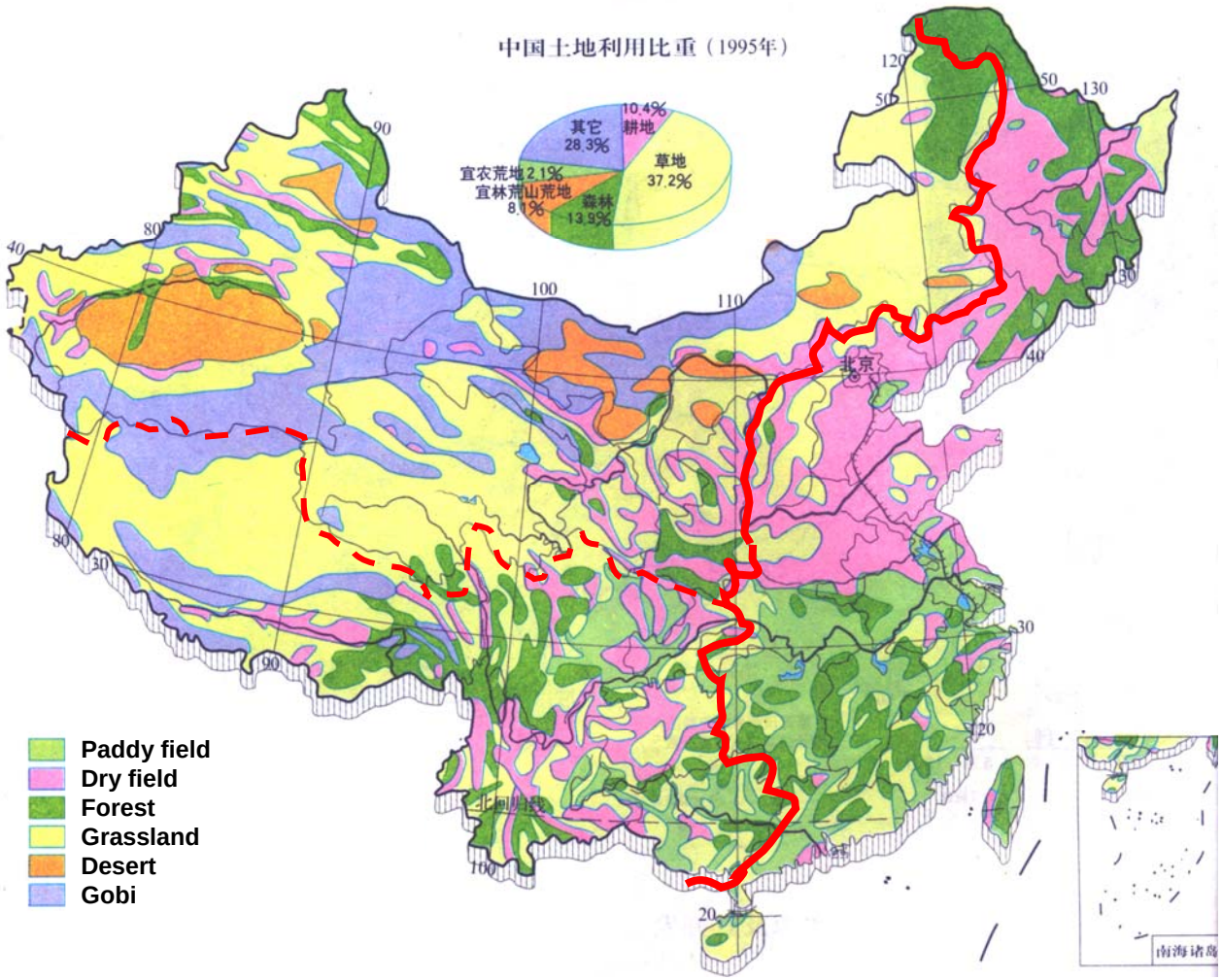
Rainfall in Western China



Water resources in Western China



Land use in Western China



Water resources by province in Western China

Region	Province	Water Resources (km^3/yr)	Population ('000)	Total Area (km^2)	Water Resources per Capita (m^3/yr)	Water Resources per Area (m^3/km^2/yr)
Northwest	Inner Mongolia	50.67	22,300	1,183,000	2,272.2	0.0428
	Shaanxi	44.19	35,700	205,600	1,237.8	0.2149
	Gansu	27.43	22,550	454,200	1,216.4	0.0604
	Ningxia	0.99	5,289	51,800	187.2	0.0191
	Xinjiang	88.28	17,000	1,660,000	5,192.9	0.0532
	Qinghai	62.62	4,956	721,200	12,635.2	0.0868
Southwest	Sichuan	254.75	77,610	485,000	3,282.4	0.5253
	Chongqing	51.14	30,430	82,400	1,680.6	0.6206
	Guizhou	103.50	36,060	176,100	2,870.2	0.5877
	Yunnan	222.10	40,490	383,300	5,485.3	0.5794
	Guanxi	188.00	46,330	236,000	4,057.8	0.7966
	Tibet	448.20	2,220	1,228,400	201,891.9	0.3649

Uneven distribution of regional water resources
- a case of Shaanxi Province

- Average: 1,200 m^3/yr·person
- Southern part (Yangtze River Basin area): more than 2,000 m^3/yr·person
- Northern part (Yellow River Basin area): 490 m^3/yr·person
- Guanzhong Plain area: 290 m^3/yr·person

2. Strategy of Water Reuse to Solve Water Shortage Problem

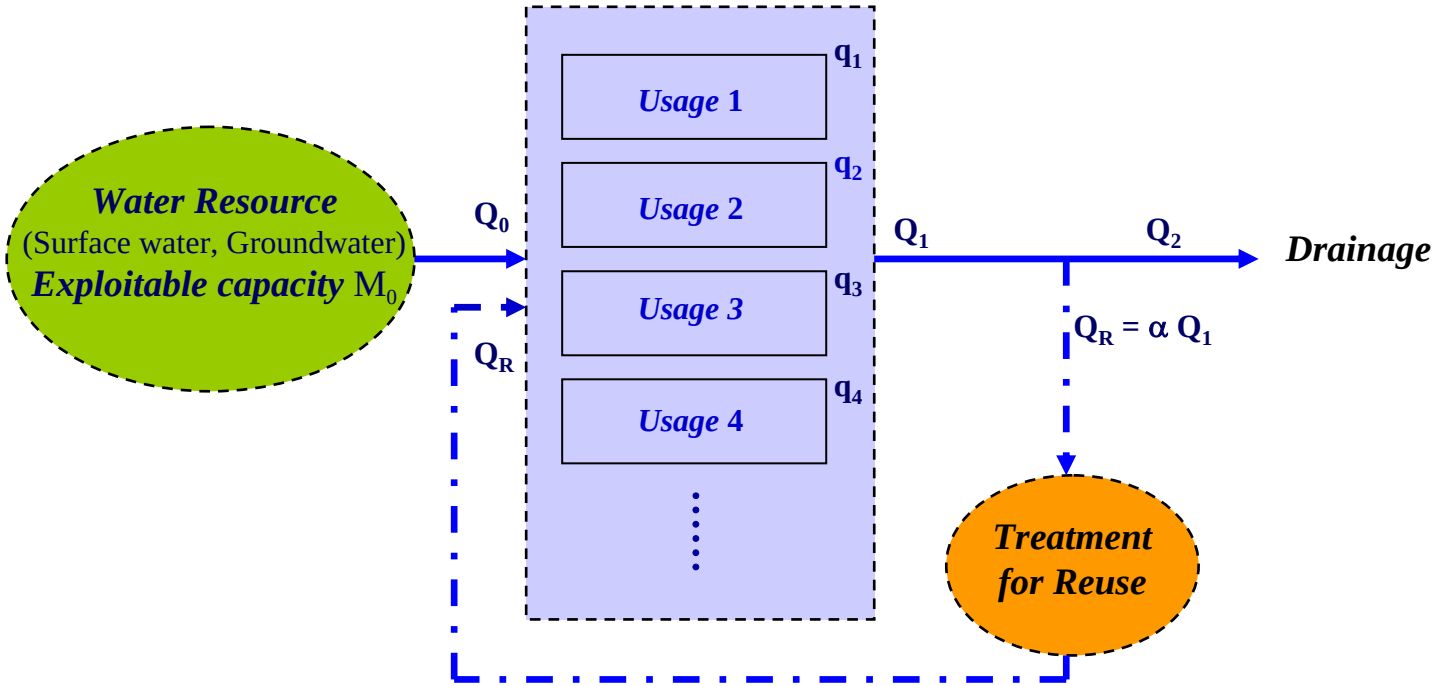
Measures to solve water shortage

- **Exploitation of new water resources** – limitation of the exploitable water resource
- **Long distance water transfer** – need of large-scale investment
- **Water recycling and reuse** – meet the principle of sustainable development

New concepts of water resources development

- **Sustainable development and utilization of water resources**
- **Wastewater is not '*WASTE*', but an important part of renewable water resource**

Water reuse for increasing the total available quantity



Case 1: Direct use and drainage (full lines)
$Q_1 = \Sigma q_i$ (i =1,2,3,4 …) $Q_0 = Q_1 = Q_2$ (neglecting loses during water use)

Case 2: Treatment for reuse (full and broken lines)
Reuse rate α, Reuse quantity $Q_R = \alpha Q_1$ (neglecting loses during water use)
$Q_1 = Q_0 + Q_R = Q_0 + \alpha Q_1 \rightarrow Q_0 = (1-\alpha)Q_1$

Principle of water resource development: $Q_0 \leqq M_0$

Types of reuse applications

- Urban reuse
- Industrial reuse
- Agricultural reuse
- Recreational reuse
- Groundwater recharge
- Augmentation of potable supplies

Requirement for urban reuse

Providing reclaimed water for nonpotable purposes within an urban area, including

- **Irrigation of recreational and landscaped areas**
- **Commercial uses such as vehicle washing etc.**
- **Construction uses such as dust control and concrete production**
- **Fire protection**
- **Toilet flushing in commercial and industrial buildings**

Urban water reuse systems

- **Water reclamation facilities for reclaimed water production**
- **Reclaimed water distribution system (*dual distribution system*), including operational storage and high-service pumping facilities**

Required water quality

	USA	China
pH	6 – 9	6.5 – 9
BOD (mg/l)	$\leq$ 10	$\leq$ 15
Color (c.u.)	–	$\leq$ 30
Turbidity (NTU)	$\leq$ 2	$\leqslant$ 10 (5 for vehicle washing)
Fecal coli. (1/100ml)	No detectable	$\leq$ 5
Cl_2 residual (mg/l)	$\geq$ 1	$\geq$ 0.2 (30 min contact)

Requirement for industrial reuse

Providing reclaimed water for industrial uses, including

- Evaporative cooling water
- Boiler-feed water
- Process water
- Irrigation and maintenance of plant grounds

Required water quality

- According to reuse purposes

Industrial water reuse quality concerns and potential treatment processes

Parameter	Potential Problem	Treatment Process
Residual organics	Bacterial growth, slime/scale formation, foaming	Nitrification, carbon adsorption, ion exchange
Ammonia	Interferes with formation of free chlorine residual, causes stress corrosion, stimulates microbial growth	Nitrification, ion exchange, air stripping
Phosphorus	Scale formation, stimulates microbial growth	Chemical precipitation, ion exchange, biological phosphorus removal
Suspended solids	Deposition, “seed” for microbial growth	Filtration
Calcium, magnesium, iron, and silica	Scale formation	Chemical softening, precipitation, ion exchange

Requirement for agricultural reuse

Providing reclaimed water for agricultural irrigation, including

- Surface (flood) irrigation
- Sprinkler irrigation
- Drip/trickle irrigation

The constituents in reclaimed water of concern for agricultural irrigation

- Salinity, sodium, trace elements, excessive chlorine residual, nutrients and bacteria

FAO guideline for irrigation water quality

Potential Irrigation Problem	Units	Degree of Restriction on Use		
		None	Slight to Moderate	Severe
Salinity (*affects crop water availability*)				
EC_w	dS/m	< 0.7	0.7 – 3.0	> 3.0
TDS	mg/l	< 450	450 – 2000	> 2000
Infiltration (*affects infiltration rate of water into the soil. Evaluate using EC_w and SAR together*)				
SAR = 0 – 3 and EC_w =		> 0.7	0.7 – 0.2	< 0.2
3 – 6		> 1.2	1.2 – 0.3	< 0.3
6 – 12		> 1.9	1.9 – 0.5	< 0.5
12 – 20		> 2.9	2.9 – 1.3	< 1.3
20 – 40		> 5.0	5.0 – 2.9	< 2.9

Continued

Potential Irrigation Problem	Units	Degree of Restriction on Use		
		None	Slight to Moderate	Severe
Specific Iron Toxicity (*affects sensitive crops*)				
Sodium (Na)				
surface irrigation	**SAR**	**< 3**	**3 – 9**	**> 9**
sprinkler irrigation	**me/l**	**< 3**	**> 3**	
Chloride (Cl)				
surface irrigation	**me/l**	**< 4**	**4 – 10**	**> 10**
sprinkler irrigation	**me/l**	**< 3**	**> 3**	
Boron (B)				
Trace Elements (see other tables)				
Miscellaneous Effects (*affects susceptible crops*)				
Nitrogen (NO_3-N)	**mg/l**	**< 5**	**5 – 30**	**> 30**
Bicarbonate (HCO_3) (*overhead sprinkling only*)	**me/l**	**< 1.5**	**1.5 – 8.5**	**> 8.5**
pH		**Normal Range 6.5 – 8.4**		

Requirement for groundwater recharge

Purposes of groundwater recharge using reclaimed water

- To establish saltwater intrusion barriers in coastal aquifers
- To provide further treatment for future reuse
- To augment groundwater aquifers
- To provide storage of reclaimed water
- To control or prevent ground subsidence

Methods of groundwater recharge

- Riverbank or dune filtration
- Surface spreading
- Soil-aquifer treatment systems
- Direct injection

Required water quality

- Site specific but for injection into potable aquifers the following is required (USA standard)

  pH = 6.5 – 8.5

  Turbidity $\leq$ 2NTU

  No detectable fecal coli./100 ml

  Residual Cl_2 $\geq$ 1 mg/l

  Meeting drinking water standard

Requirement for augmentation of potable supplies

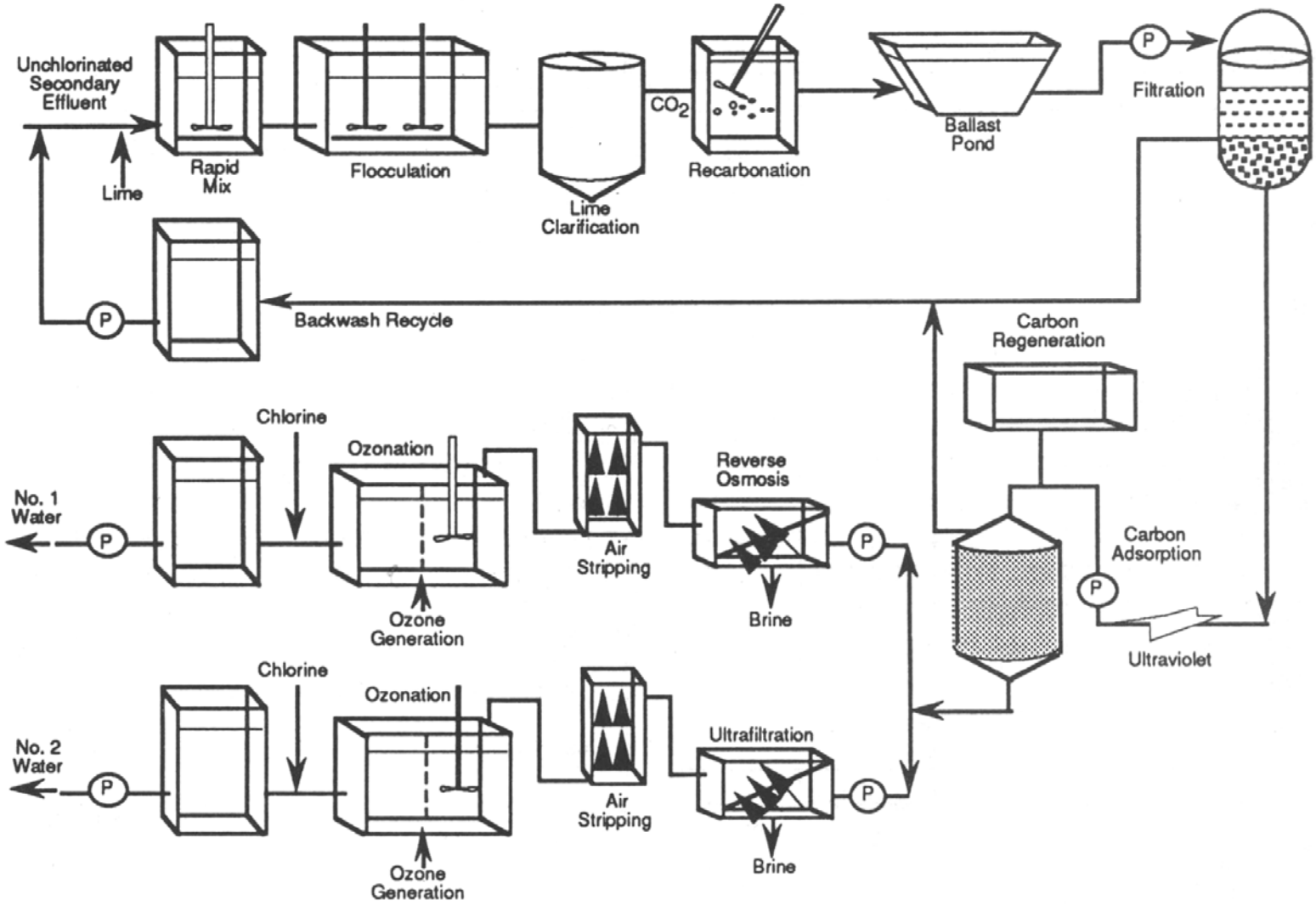
Indirect potable water reuse

- Discharge of treated wastewater into water bodies which function as potable water sources
- Much higher quality is required for nonpotable reuse

Direct potable water reuse

- Only one city in the world – Windhoek, Namibia (operated intermittently)
- Extensive researches or demonstrations are underway

Potable reuse demonstration treatment processes at Denver, USA



3. Considerations on Water Reuse for the Arid Area in Western China

Objective of water reuse

To mitigate water shortage and to improve the environment at the same time

- Deterioration of biological environment is the main problem in Western China
- The problem is related to and resulted from water deficiency
- Environment restoration is among the prime tasks of Western Development

Priority uses of reclaimed water

- **Urban reuse** especially for afforesting, gardening, large and small scale landscaped areas
- **Industrial reuse** to reduce its demand for fresh water supply
- **Groundwater recharge** – optional in a city area such as Xi'an where water table depletion and ground subsidence are serious problems

Water treatment for reuse

Centralized wastewater treatment and reuse

- In city areas where secondary treatment is performed – *advanced treatment* of the secondary effluent for reuse purposes

Decentralized wastewater treatment and reuse

- In smaller towns or residential areas where wastewater treatment is to be performed – consideration of *direct treatment* of wastewater for reuse purposes

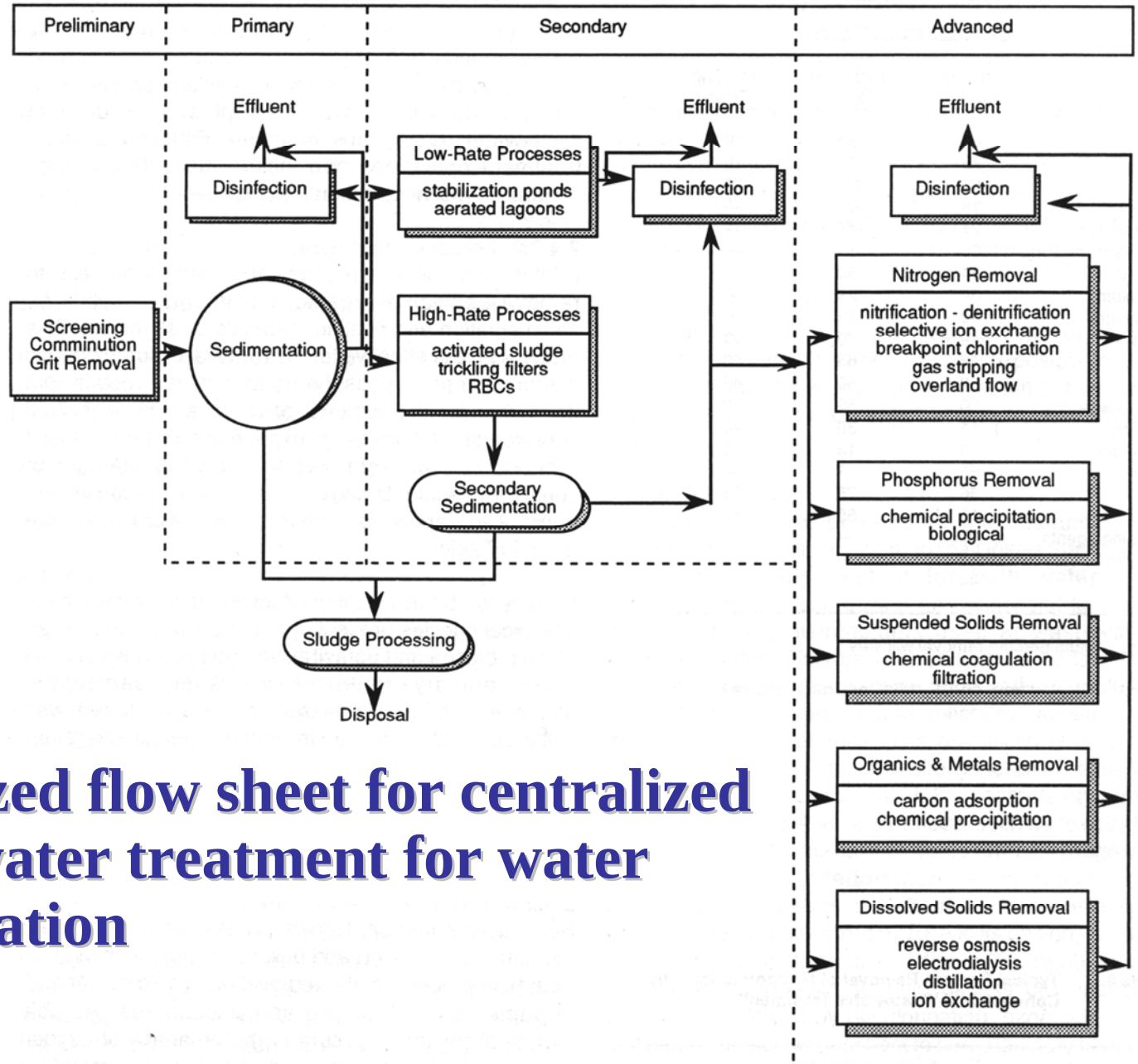
Technological and economic consideration

Economic requirement on wastewater treatment

- Low cost for construction, operation and maintenance
- Cheap price for consumption of reclaimed water

Technological requirement

- Short treatment process train
- Highly efficient impurity removal
- Low energy consumption for treatment



Generalized flow sheet for centralized wastewater treatment for water reclamation

Decentralized (on-site) wastewater treatment and water reclamation

- Lagoon treatment
- Anaerobic treatment systems
- Enhanced physicochemical systems
- Biological/chemical treatment systems
- Innovated septic (johkasou) systems
- Membrane bioreactor
- Pelleting bioreactor
- Aerobic granular sludge bioreactor

4. Tasks of Study on the Recycling and Reuse of Water Resources for the Arid Area in Western China

Task 1: Basic study on the system of water reuse and its optimization

- The value model of recycled water resource for the sustainable development of western China
- System dynamic (SD) model of water recycling and reuse
- Optimized utilization of recycled and conventional water resources

Task 2: Study on the reuse-water quality standards and treatment technologies

- **Water quality standards in accordance with reuse purposes**
- **Enhancement of conventional wastewater treatment technologies and optimized integration of treatment system to achieve high efficiency and energy saving**
- **Ecological/biological treatment technologies**

Task 3: Environmental risk assessment of water reuse

- Methods and criteria of environmental risk assessment of water reuse
- Risk assessment on secondary environmental pollution related to water reuse
- Safety assessment of utilization of recycled water

Task 4: Socio-economical and managerial study of water reuse

- Socio-economical evaluation of water reuse
- Management of water-reuse systems
- Information and to decision-supporting systems

Task 5: Water reuse systems and pilot study

- Environmental/ecological water reuse system in urban area
- Urban water reuse system
- Integrated water reuse system
- Water conservation measures


Western Development –
Heavy Tasks for
More than One Generation