TECHNOLOGIES AND STRATEGIES USED IN OKINAWA

Third Symposium on Hawaii/Okinawa Water Resources

held in conjuction with the
Fourth WRRC Conference

Appropriate Technologies and Issues for Water Resources Management on Tropical Islands in the Asia/Pacific Region

at the
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FOREWORD

This Symposium on Hawaii/Okinawa Water Resources (SHOWR) is the third in a series of conferences which began over 10 years ago in Okinawa. The first SHOWR conference convened in January 1987 just outside the University of the Ryukyus at the Ginowan Seminar House, Okinawa Prefecture, Japan. The theme was "Water Resources Perspective: Okinawa, Hawaii, and Micronesia." A proceedings (May 1991) with that title was jointly published by the University of Hawaii Water Resources Research Center and the University of the Ryukyus. The second SHOWR conference was held in December 1991 on Miyako Island in Okinawa Prefecture. Its focus was on the problems of groundwater quality in insular environments. The papers presented appear in a special issue of *Galaxea* (Dec. 1994), a journal of the Sesoko Marine Center, University of the Ryukyus. The two earlier symposia featured mostly academic papers by faculty members from both the University of Hawaii and the University of the Ryukyus. Academic-level exchanges between our two faculties are conducted under the Basic Agreement on International Exchange Between the University of Hawaii and the University of the Ryukyus.

Water problems of Hawaii, Okinawa, and other tropical islands are not only topics of scholarly interest; they also involve increasingly pressing issues of common interest that are being confronted by decision makers at all governmental levels throughout the Pacific island region. Recognizing the need to share experiences and exchange technologies, the University of Hawaii Water Resources Research Center organized its Fourth WRRC Conference in June 1996 with the theme "Appropriate Technologies and Issues for Water Resources Management on Tropical Islands in the Asia/Pacific Region." In this broad regional context, special sessions on technologies and strategies used in Okinawa were organized and key experts from the prefectural water agencies were invited to participate. English summaries of their presentations were published in the widely distributed "Abstracts and Assessments" of the conference (WRRC Special Report SR-97-01). The conference was by far the largest Pacific islands freshwater conference ever convened, with over 200 participants from throughout the region attending three full days of parallel sessions. More than 60 papers, speeches, and poster papers were presented.

A note on Class 2 Rivers is provided here for clarification. Class 2 Rivers in Okinawa are for all practical purposes streams, often with intermittent flows, typical of tropical island environments. They are referred to as rivers because under the Japan River Law, all natural water courses fall into three river classes for jurisdictional purposes. Class 1 Rivers are especially important for the conservation of national lands and for the national economy. Class 2 Rivers are important to prefectural interests and are designated by the prefectural governments. Other rivers, Class 3, are managed by lower-level (city–town–village) jurisdictions. In the case of Okinawa, all major rivers have been designated as Class 2, which ordinarily would fall under the jurisdiction of the prefectural government. However, under a Special Steps Law for the Promotion and Development of Okinawa, the National Ministry of Construction is authorized to improve, maintain, and repair these Class 2 Rivers and to construct multipurpose dams that are heavily subsidized with funding from the national government. Thus, the Class 2 Rivers of Okinawa are, in effect, treated as Class 1 Rivers, and the use of the word river serves a useful connotation.

For the production of this proceedings volume we owe a special gratitude to the dedicated efforts of Karen Tanoue, WRRC editor, and her diligent staff, April Kam and Patricia Hirakawa.

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第３回ハワイ－沖縄水資源シンポジウム

沖縄における技術と戦略

序文

この報告は，沖縄で１０年前に始められた一連のハワイ－沖縄水資源シンポジウム（SHOWR; Seminars on Hawaii-Okinawa Water Resources）の第３回目にあたる．

SHOWR I は，１９８７年１月に琉球大学に近い宜野湾セミナーハウスで行われた．その際のテーマは「島嶼水環境の展望－沖縄，ハワイ，ミクロネシアのアプローチ」であった．セミナーは多数の参加者を得ることでができ，１９９１年５月にはプロシーディングが，同名のタイトルでハワイ大学水資源研究センターと琉球大学の共同で発行された．

SHOWR IIは，１９９１年１２月に宮古島で行われ，島嶼環境の水質問題に焦点が当てられた．そのときの報告の成果は論文集としてまとめられ，１９９４年１２月に琉球大学瀬底臨海センターの定期刊行物であるギャラクシアに掲載された．これらの二つのセミナーは主として，ハワイ大学と琉球大学の研究者による学術的な報告によって構成されていた．このような両大学の学術レベルでの交流は，ハワイ大学と琉球大学の間で締結された国際交流協定に基づいている．

しかしながら，ハワイや沖縄，そして他の熱帯の島嶼の水に関する問題は単に学術的な興味の対象に止まらない．太平洋の島嶼地域全体を通じて，あらゆる意思決定者が，島の水資源の問題に直面している．それらは問題の度を深めており，共通の関心として，さまざまな課題を含んでいる．経験を分かち合い，技術を交換する必要性にかんがみて，ハワイ大学水資源研究センターは，１９９６年６月に「アジア／太平洋地域の熱帯島嶼における水資源管理に関する適正技術と課題」と題して，第４回WRRC会議を開催した．この広範な地域に関する諸課題の中で，沖縄に関する特別セッションが持たれ，沖縄県の水関連機関の専門家が招請された．会議全体の英文による短い要約集は「会議の梗概と評価」（WRRC特別報告SR-97-01）として，すでに出版され，広く配布された．この会議そのものは，太平洋島嶼の淡水に関するこれまで行われた会議の中で，もっとも大規模のものである．対象とする地域全域から２００名を超える参加者が，３日間にわたって行われた複数の分科会に参加した．そして６０以上の論文が提出され，講演，ポスターの発表が行われた．このSHOWR III の報告集は沖縄特別分科会で発表されたときの資料を掲載している．

最後に，この予稿集の編集にあたっては，とりわけ，水資源研究センターの編集者であるカレン・タノウエさん，そしてそのスタッフであるエイプリル・キムさん，パット・ヒラカワさんの多大な努力によっている．この場を借りて，特に感謝の意を表したい．

CONTENTS

沖縄県における水資源の概要

小渡昭利

要約

沖縄県の島々は亜熱帯域にある．気候は年間を通じて暖かく，年平均気温は摂氏２２度で，一年の温度変化は，冬の１０度から夏の３２度の間である．年平均の降水量は約２２００ｍｍで，５月から６月にかけての梅雨と，８月から９月にかけての台風の時期にもたらされる．島嶼は土地が限られているため，河川は比較的短く，勾配が急で，降雨時には洪水が沿岸に流れ出る．高い大きな山はほとんどなく，それゆえ集水域は比較的小さい．このような地形的な特徴からほとんどの川で平水量は低い．

現在，本島の主要な水源はダムや河川，地下水で，約４万４千立方メートル／日が供給されている．水源別にみた水量の内訳は６０％がダム，河川が２８％，地下水１１％，他の水源が０．５％となっている．

沖縄の水需要は，人口の増大，生活水準の上昇，産業開発，そして観光客の増大によって上昇してきた．しかしながら，この継続的に増大する水需要を満たすため，水供給の増大をはかるには不確実性をともない，また困難が増すと予想される．このことから，沖縄県は環境保全に配慮しつつ，水質，水量を改善するための安全な水源として，多目的ダムの建設を進めている．また，他の方策として，地下水の開発や海水淡水化施設の建設がある．

沖縄では水不足は常態となっている．１９７２年以来８年間を除き，ほぼ毎年のように断水が生じる．もっとも厳しい断水は１９８１年から８２年にかけての３２６日にわたる断水で，また最近では，８８年に３３日，８９年に２６日，９１年に６４日，９３年に３１日と続いている．９４年は全国で深刻な水不足が生じたが，幸い沖縄では梅雨と台風により豊富な水量が確保できた．水不足の際には，断水を公式に決定するために多数の国や県の機関相互で調整がはかられる．

水の再利用プログラムが強く求められている．水不足を解消するために，雨水利用，井戸水利用が現在も行われており，これらも有効に使われなければならない．また，排水の再利用も可能である．このような方策を進める上にも，沖縄の水資源には限りがあり，水はすべてに便益をあたえる公共の財産であることを周知する必要がある．人々に水の保全の大切さを訴え，「節水型社会（economy-oriented society）」を生みだすことが重要である．

WATER RESOURCES IN OKINAWA PREFECTURE: AN OVERVIEW

Akitoshi Odo[1]

GEOGRAPHICAL CHARACTERISTICS

The islands of Okinawa Prefecture are in the subtropical zone. The weather there is warm throughout the year, with an average annual temperature of 22°C. Extremes range from 10°C (in the winter) to 32°C (in the summer). Annual rainfall averages about 2200 mm, but its occurrence is highly seasonal in two wet periods, a *baiu* season (May–June) and a typhoon season (August–September). Since the islands are limited in land area, the rivers are relatively short with steep slopes and rapid runoffs into coastal waters. There are very few large mountains with high elevations, and the watershed areas are relatively small. Water levels of most of the rivers are usually low.

WATER RESOURCES

Presently, the major water supply sources include dam reservoirs, rivers, and underground aquifers. Approximately 44 100 m^3/d of water are supplied from these and other sources. Dams account for about 60.1% (26 500 m^3/d); rivers, 28.3% (12 500 m^3/d); groundwater, 11.1% (4900 m^3/d); and other sources, 0.45% (200 m^3/d).

PROSPECTIVE WATER DEMAND AND FUTURE PLAN

Water demand in Okinawa Prefecture is expected to rise due to an increasing population, improved living standards, industrial development, and an increasing number of tourists. However, the prospects of increasing the water supply to satisfy this rising demand remains uncertain. Since it is expected to become increasingly difficult to meet the continuously rising water demand, the Okinawa Prefectural Government has been promoting the construction of multipurpose dams that will provide a secure source of water of improved quality while taking into account environmental protection factors. Other prefectural projects to improve the water supply situation in Okinawa include the development of groundwater resources and the construction of desalination facilities.

The limited water resources in Okinawa should be recognized by its people as public property for the benefit of all. Water reuse programs are strongly recommended. In this context, there are other measures to overcome water shortfalls in Okinawa. Rainwater and spring water are currently underutilized and should be efficiently used, and certain types of drainage water can be treated and recirculated for reuse. It is also vital to remind people of the importance of water conservation and, in that context, promote the formation of an "economy-oriented society."

[1]Deputy Councilor, Regional Promotion Division, Department of Planning and Promotion, Okinawa Prefectural Government, Izumizaki 1-2-2, Naha, Okinawa, JAPAN.

WATER SHORTAGES

Water shortages are common in Okinawa. Except for eight years, water rationing has been imposed almost every year since 1972. The worst drought occurred during 1981–82 when intermittent water rationing occurred over 326 days. More recently, water rationing occurred for 33 days in 1988, 26 days in 1989, 64 days in 1991, and 31 days in 1993. However, in 1994, when many places on the Japanese mainland were suffering from extreme drought conditions, there was no rationing in Okinawa due to sufficient rainfall from typhoons and other climatic factors.

In times of shortages, official decisions on water rationing are coordinated among the following national government and prefectural-level entities:

- Okinawa Water Shortage Measures Liaison Committee

  Office: Construction and Administration Section, Development and Construction Division, Okinawa General Bureau, Government of Japan

- Okinawa Prefectural Water Shortage Measures Main Council

  Office: Regional Promotion Division, Department of Planning and Development, Okinawa Prefectural Government

- Okinawa Prefectural Enterprise Bureau, Water Shortage Measures Headquarters

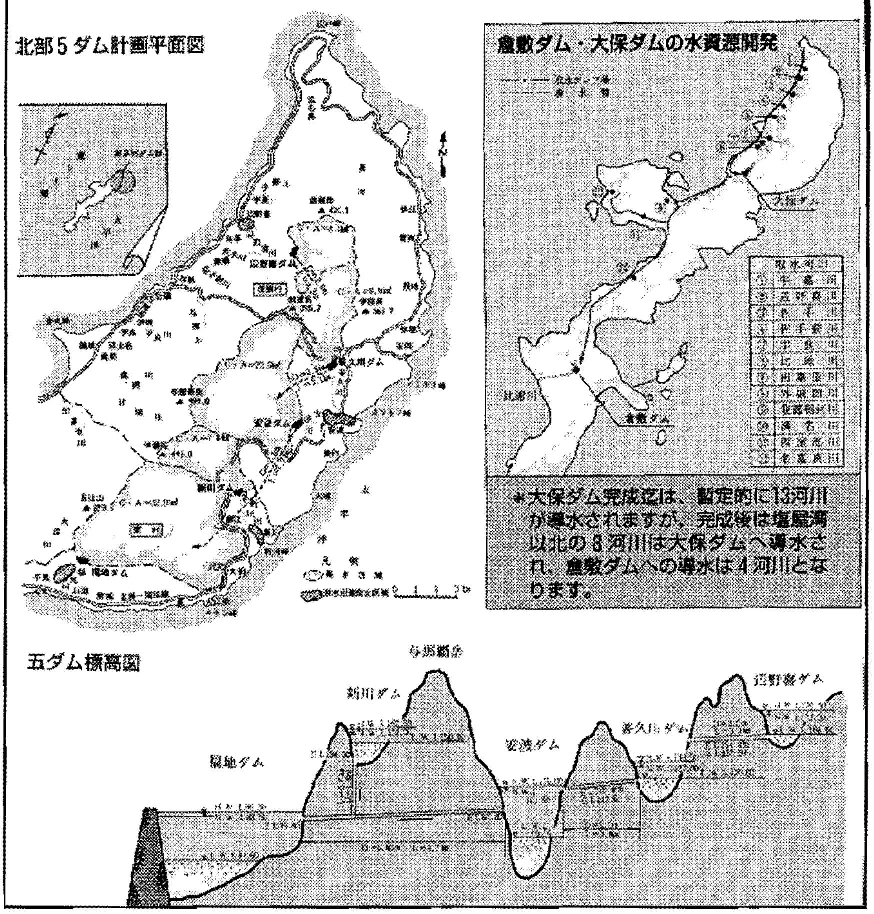
  Office: Regional Promotion Division, Department of Planning and Development, Okinawa Prefectural Government

THIRD PROMOTION AND DEVELOPMENT PROJECT OF OKINAWA PREFECTURE

The following pages provide information on water resources development projects as presented in the "Policies and Outline of Third Promotion and Development Project of Okinawa Prefecture." The two figures were reproduced from "DAM" (a brochure by the North Dam Office, 1994). The original figures were printed in color.

ダムによる水資源開発

沖縄本島の河川は、流域面積が小さく、流況が不安定なため、水資源開発の効率が悪いという特徴があります。このため、ダム建設による水資源開発を行う場合にも、他のダムと結びつけて流域面積を大きくしたり、河川から取水した水を導水して貯留するなど、水資源開発の効率を上げるよう工夫がなされています。



WATER RESOURCES DEVELOPMENT THROUGH DAMS

Rivers in Okinawa are characteristically ineffective for water resources as they are provided with small catchment areas and unstable supples. Therefore, devices are introduced to make the storage of water efficient by increasing catchment areas, with interconnecting dams as well as intaking water from rivers.

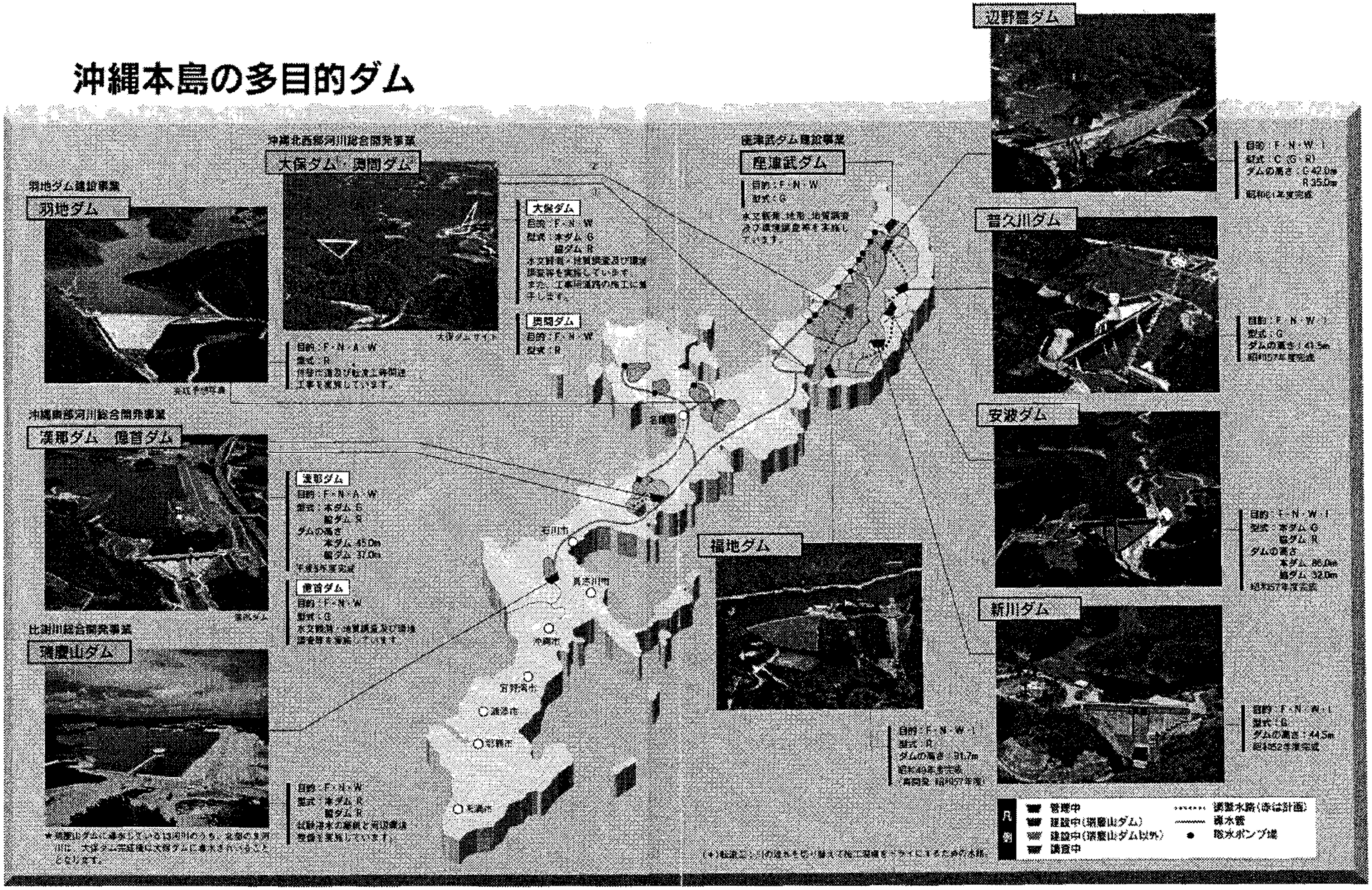
北部５ダム計画平面図－ Diagram of Five Dams in Northeastern Okinawa

ダム標高図－ Diagram of the Elevation of Five Dams

東シナ海－ East China Sea	**集水区域－ Catchment Area**
太平洋 － Pacific Ocean	**洪水氾濫防止区域－ Flood Control Area**
東系列ダム群－ Northeast Group of Dams	
辺戸岬 － Cape Hedo	**与那覇岳－ Mt.Yonaha**
イシキナ崎－ Ishikina Point	**倉敷・大保ダムの水資源開発**
カツセノ崎－ Katsuseno Point	**Water Resources Development through Kurashiki and Taiho Dams**
新川崎 － Arakawa Point	**取水ポンプ－ Intake Pumps**
キナン崎 － Kinan Point	**導水管－ Raw Water Main**
国頭村 － Kunigami Vil.	**比謝川－ Hija River *～川 ＝～ River**
東村 － Higashi Vil.	**取水河川－ Rivers of Water Sources**

*Raw water from 13 rivers will be stored at and drawn from Kurashiki Dam until the completion of Taiho Dam. After its completion, 8 rivers located to the north of Shioya Bay will be conducted to Taiho Dam and that of the remaining 4 rivers to Kurashiki Dam.

沖縄本島の多目的ダム



沖縄北西部河川総合開発事業
大保ダム・奥間ダム
大保ダム
奥間ダム
羽地ダム建設事業
羽地ダム
沖縄東部河川総合開発事業
漢那ダム　億首ダム
漢那ダム
目的：F・N・A・W
億首ダム
目的：F・N・W
比謝川総合開発事業
瑞慶山ダム
目的：F・N・W
座津武ダム建設事業
座津武ダム
目的：F・N・W
辺野喜ダム
目的：F・N・W・I
普久川ダム
目的：F・N・W・I
ダムの高さ：41.5m
安波ダム
目的：F・N・W・I
福地ダム
目的：F・N・W・I
ダムの高さ：31.7m
新川ダム
目的：F・N・W・I
ダムの高さ：44.5m
凡例
管理中
建設中(瑞慶山ダム)
建設中(瑞慶山ダム以外)
調査中
調整水路(赤は計画)
導水管
取水ポンプ場

Measures on Water Resources Development Based on the Third Okinawa Promotion and Development Project of Okinawa Prefecture

Measures	Content and Scale of Measures	Progress	Remarks
Water Resources Development Construction of Multipurpose Dams <Central & Prefectural Governments>	(1) Haneji Dam Project Type: Rockfilled Dam Height: 66.5 m Reservoir Area: 1.15 km^2 Total Volume: 19 800 000 m^3 Normal Storage: 19 200 000 m^3 Usable Volume Water Supply: 12 000 m^3/d Irrigation Water: 83 800 m^3/d (farmland 1,341 ha)	5/72 Preliminary studies for the dam project begun 4/76 Survey for construction plan begun 4/81 Construction commenced 9/84 Basic plan made public 10/92 Contract concluded for standard compensation for land 11/95 Memorandum concluded for the construction of the main dam 3/96 Construction of the main dam began	Planned for completion in 2001.
	(2) Integrated Development Project of Rivers in Eastern Okinawa Construction of adjusting water channel between the Okukubi and Kanna Dams. Existent Kin Dam will be extended and renamed Okukubi Dam.		
	(a) Kanna Dam Type: Concrete Gravity Dam Height: 45.0 m Reservoir Area: 0.55 km^2 Total Volume: 8 200 000 m^3 Normal Storage: 7 800 000 m^3 Usable Volume Water Supply: 11 500 m^3/d Water for Agriculture: 12 000 m^3/d	4/29 Survey for construction plan begun 4/82 Construction commenced 3/83 Basic plan made public 3/93 Alteration of basic plan made public 3/93 Completed and put under management	Publicized the alteration of project from Kanna Dam to Integrated Development Project of Rivers in Eastern Okinawa.

Measures—*Continued*

Measures	Content and Scale of Measures	Progress	Remarks
	(b) Okukubi Dam Redevelopment project on Kin Dam. Type: Concrete Gravity Dam Height: 41.5 m Reservoir Area: 0.61 km^2 Total Volume: 7 600 000 m^3 Normal Storage: 6 900 000 m^3 Usable Volume Water Supply: 8 200 m^3/d	4/93 Integrated Development Project of Rivers in Eastern Okinawa begun (construction of Okukubi Dam)	
	(3) Integrated Development Project of Rivers in Northern Okinawa Construction of adjusting water channel between the Taiho and Okuma Dams. Eight rivers will be conducted to Taiho Dam. (a) Taiho Dam Type Main Dam: Concrete Gravity Dam Side Dam: Rockfilled Dam Height Main Dam: 77.5 m Side Dam: 75.0 m Reservoir Area: 0.89 km^2 Total Volume: 20 050 000 m^3 Normal Storage: 19 350 000 m^3 (a) Okuma Dam Redevelopment project on Kin Dam. Type: Rockfilled Dam Height: 81.0 m Reservoir Area: 0.23 km^2 Total Volume: 3 550 000 m^3 Normal Storage: 3 310 000 m^3 Usable water is conducted from Taiho Water Supply: 111 000 m^3/d	5/72 Preliminary studies for the dam commenced 5/87 Survey for construction plan begun 6/90 Construction commenced 8/93 Detailed construction plan decided and publicized (Taiho and Hija Rivers) 3/95 Roadbuilding in relation to Taiho Dam commenced 11/95 Terms submitted by Ogimi Village 6/96 Contract concluded for standard compensation for loss of land and facilities (Taiho Dam)	

Measures—*Continued*

Measures	Content and Scale of Measures	Progress	Remarks
	(b) Hija River Integrated Development Project Redevelopment of Zukeyama Dam, exclusively for water supply, with cooperation of the Central Government and Okinawa Enterprise Bureau. Kurashiki Dam (renamed from Zukeyama Dam) Type Main Dam: Concrete Gravity Dam Side Dam: Rockfilled Dam Height Main Dam: 33.5 m Side Dam: 15.0 m Reservoir Area: 0.77 km^2 Total Volume: 7 150 000 m^3 Normal Storage: 6 900 000 m^3 Usable Volume Water Supply: 28 800 m^3/d	5/72 Zukeyama Dam completed by the United States Civil Administration of the Ryukyu Islands 4/79 Preliminary studies for the dam project commenced 4/82 Construction commenced 3/93 Contract concluded for cooperative project on Zukeyama Dam between the Central and Prefectural Governments 12/88 Contract concluded for standard compensation for land and facilities 3/89 Construction of the main dam begun 1/94 Trial impoundment commenced 6/96 Construction completed	The storage volume will be tripled with this project. Water is conducted from the North Side Rivers.
Integrated Northwest Side Reservoirs Development Project <Central and Prefectural Governments>	Secure stable storage at the Zukeyama and Taiho Dams by conducting excess water from the Northwest Side Rivers. (1) Intakes Intake pumps (two places) (Gabusoka and Nakama Rivers)	(Consulting the local authorities)	13 facilities (planned) 11 completed (by 1995) Average volume 42 300 m^3/d
	(2) Facilities for Water Conduction Water conduction project of the main Northwest Side Dam	Under construction Raceway—total length expected 132 km; 79 km completed	
	(3) Storage Facilities Redevelopment of Zukeyama Dam	Renamed Kurashiki Dam under management of the Prefectural Government (from April 1, 1996)	Now intakes 71 000 m^3/d

Measures—*Continued*

Measures	Content and Scale of Measures	Progress	Remarks
Municipal Water Resources Development <Prefecture/ Municipalities>	(1) Groundwater Development		
	(a) Groundwater survey at municipalities in isolated islands	1992 survey completed (all Okinawa islands)	
	Trial Boring 37 cases Electronic Survey 7 cases Hydrogeologic Map 13 Geological Boring 4 cases Water Quality Analysis 9 cases Spring Water Survey 1 case Surging Test 1 case Actual Condition of Spring/Well Water 1 case (all Okinawa islands) Unutilized Water Sources 2 cases Groundwater Development Survey 1 case Total 76 cases	As conduction of water from rivers is difficult in island municipalities, we will continue surveying for groundwater, the main water source in these areas.	
	(b) Groundwater development in Okinawa Island (Enobi, Gushikawa City) Supply (1996) 8 000 m^3/d	(Consulting the local authorities)	
	(2) Promotion of Small-Type Multipurpose Dam		
	Gakiya Dam (Iheya Village)	Under construction.	
	Type Concrete Gravity Dam Height 38.0 m Reservoir Area 0.05 km^2 Total Volume 297 000 m^3 Normal Storage 274 000 m^3 Usable Volume Water Supply 70 m^3/d	During 1997, adjustments made (roadbuilding and purchase of lands) for dam construction.	

Measures—*Continued*

Measures	Content and Scale of Measures	Progress	Remarks
Construction of Desalination Facilities <Prefectural Government>	Construction of desalination facilities as a part of various water resources development projects in Okinawa Island. • Facility Chatan Filtration • Amount Developed 1995 10 000 m^3/d 1996 25 000 m^3/d 1997 40 000 m^3/d • Outline of Facility Place: Chatan Plottage: 12 000 m^2 (approx.) Building Area: 9 000 m^2 (approx.) Output Volume: 40 000 m^3/d Desalination Method: Reverse Osmosis Recovery Rate: 40% (approx.) Type of Membrane: Sprial Type—Polyamide (RO membrane) Intake: Submarine Intake Pipe Discharge: Underwater Defusing Method Total Cost: ¥ 34.7 billion	As of 1996, the facility (supply capacity of 25 000 m^3/d) completed and partially in operation.	
Water for Agricultural Use	Development of Various Water Resources and Facilities Effective use of ground and river waters. "Supply and Demand Plan of Water for Agricultural Use" decided in 1992. Area (ha) / Volume (1000 m^3/yr) Overall Plan: 46 400.0 / 189 447.9 Objectives for 2001: 24 000.0 / 99 973.9 Dams and Rivers: 11 563.0 / 61 967.8 Underground Reservoir: 10 119.0 / 31 290.0 Rainwater Catchment: 2 318.0 / 6 716.1	Progress of the development program of water for agricultural use by 1995: Area Benefited: 15 021 ha Percentage of Provision Out of Total Plan: 32.4%	

Measures—*Continued*

Measures	Content and Scale of Measures	Progress	Remarks
Efficient Use of Rainwater	Appropriate Use of Unused Water • Promote efficient use of rainwatrer by creating a manual and guidelines under "Promotion Policies for Efficient Use of Water Resources in Okinawa Prefecture." • Financing method for provision of rainwater utilization facilities • Premium financing system for construction of rainwater utilization facilities (Housing Loan Cooperation). The system provides those who purchase or build new houses with loans at premium rates, for purchasing rainwater recycling facilities to balance the demand and supply of water.	• Promotion Policies for Efficient Use of Water Resources in Okinawa Prefecture (put into force 1992) • Guidelines for Rainwater Usage • Rainwater Usage Manual (compiled 1992) • Technical Policies for Rainwater Usage (compiled 1994) Introduced in 1991 Amount of Loan ¥ 500 000	"1997 Rainwater Fair in Okinawa" to be held.
Promotion of Recycling of Purified Sewage Water	Consideration of Sewage Water Recycling in Extensive Areas Water highly treated in sewage disposal plants recycled for flush toilet water.	Construction of drains for recycled water. Decision to use recycled water for flush toilets made by the Department of Civil Engineering and Construction, Okinawa Prefectural Government.	
Improvement and Maintenance of Water-Retaining Forests	Afforestation of Water-Retaining Forests Project funded by the Okinawa Water Resources Foundation (subsidize half the amount; the other half to be borne by municipalities).	Amount subsidized between 1979 and 1995: Subsidy ¥ 182 919 000 Area 2 069 ha	
Development of Reservoir Areas	Promotion of Reservoir Areas Undertaking of projects stipulated in memorandum.	Promotion of municipal reservoir areas with privileged subsidies from the National Treasury and Okinawa Water Resources Foundation.	

沖縄県におけるダム計画

上唐利夫

要約

流域のこう配が急であることや，他の地質的な特徴から，沖縄県の河川は一般的に流量が安定せず，また降雨時や降雨後の短時間のうちに流出する傾向がある．また，河川は局地的な豪雨によって水位が上がり，洪水をひきおこし，沿岸部にかなりの被害をたびたび与えている．

そこで，多目的ダム計画，すなわち，河川改修や灌漑用水供給などを目的とした計画が，沖縄の開発にとって重要な役割を演じる．ダム計画は，国によるものと，県の補完的なダム計画と大きくは二つにわかれる．

国の河川法のもとでは，一級河川は国の制度下にある．沖縄には一級河川が存在しないが，沖縄開発特別措置によって，指定された地域の水開発計画は国の建設省の管理下で直接実施される．

近年，小規模ダム計画事業が強調されてきている．この事業は，旧来のダム開発の恩恵からもれ落ちてきた山間部や離島の河川改修，灌漑用水供給に焦点があてられる．山間部や半島，離島のようなローカルな地域では，水需要が相対的に小規模であり，渇水期の水供給や，水質の維持に，多数の問題をかかえている．また，これらの地域では，河川改修がほとんど行われておらず，また，改修された川でも，水安全度の程度は他の地域に比べて極端に低い．このような未開発な地域は，国や県企業局管理の旧来のダム開発の便益を受けるには不利な状況にある．

国の補助政策による小規模ダム事業が１９８８年に始まった．小規模な地域河川を改修し，近接地域に灌漑用水を供給するものである．開始後，９５年までの間に，３７県で計１０７事業（多目的ダム事業９６，河川改修事業１１）が実施された．ダム事業により，近接地域に水が供給されるため，地域の人々により歓迎され，「村民による，村民の，村民のためのダム」といわれている．地域の生活向上のために寄与すべく大きな期待を担っているといえよう．

DAM PROJECTS IN OKINAWA PREFECTURE

Toshio Ueto[1]

Due to the steep inclines of river basins and other geological conditions, rivers in Okinawa Prefecture that normally do not have a steady flow of water tend to overflow in a short time during and after it rains. The rivers tend to rise and flood due to localized torrential rains and often result in extensive damage to coastal areas. Therefore, multipurpose dam projects, such as those which focus on improving rivers and supplying irrigation water have played an important role in the development of Okinawa Prefecture. There are two types of projects related to dams: the first is dam projects under the supervision of the national government, and the second is supplemental dam projects under the supervision of the prefectural government.

DAM PROJECTS UNDER THE SUPERVISION OF THE NATIONAL GOVERNMENT

Under the National River Law, large Class 1 Rivers fall under the jurisdiction of the national government. Although in Okinawa there are no Class 1 Rivers, the Okinawa Development Special Measures Act provides for water projects in designated areas to be carried out under the direct control of the national Ministry of Construction. Table 1 includes information on both completed dam projects and those which are still under construction in Okinawa.

SUPPLEMENTAL DAM PROJECTS UNDER THE SUPERVISION OF THE PREFECTURAL GOVERNMENT

Dam projects that receive subsidies from the national government but are under the supervision of the prefectural government are summarized in Table 2. Recently, the emphasis has been on planning projects for "small-scale dams." The focus of these projects are on local river improvements and irrigation water supply in mountainous regions and islands that fall beyond the reach of benefits from conventional dam projects.

Water demand in local areas (such as mountainous regions and peninsulas) and in remote islands is relatively small: only a few hundred cubic meters per day. There are a number of problems concerning the maintenance of the water supply and water quality during periods of water shortage. Moreover, in these underdeveloped regions, few river improvements have been made, and the water safety levels of the improved rivers are typically lower than those of other regions. These underdeveloped/depressed regions have difficulty in receiving benefits from conventional projects under the supervision of the national government and the Enterprise Bureau of Okinawa Prefecture.

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TABLE 1. Dam and Reservoir Projects Under National Government Control

Dam and Reservoir	Completed Projects: Fukuchi Dam	Arakawa Dam	Aha Dam	Fungawa Dam	Benoki Dam	Kanna Dam	Total	Projects Under Construction: Haneji Dam	Okukubi Dam	Taiho Dam	Okuma Dam
Purpose[a]	F.N.W.I.	F.N.W.I.	F.N.W.I.	F.N.W.I.	F.N.W.I.	F.N.A.W.		F.N.A.W.	F.N.W.	F.N.W.	F.N.W.
Catchment Area (km^2)	32.0	7.4	22.5	8.9	8.1	7.6	86.5	10.9	14.6	13.3	4.8
Reservoir Area (km^2)	2.54	0.16	0.83	0.31	0.50	0.55	4.89	1.15	0.61	0.89	0.23
Reservoir Volume (10^3 m^3)											
Total	55 000	1 650	18 600	3 050	4 500	8 200	91 000	19 800	7 600	20 050	3 550
Normal Storage	52 000	1 250	17 400	2 550	4 000	7 800	85 000	19 200	6 900	19 350	3 310
Flood Control	7 300	650	4 800	1 600	2 400	1 150	17 900	3 600	2 500	2 150	500
Usable											
Nonspecific Uses	2 000	100	200	150	150	240	2 840	2 600	1 900	1 320	720
Municipal Uses											
Domestic	31 400 (86 800 m^3/d)	370 (13 200 m^3/d)	9 130 (55 200 m^3/d)	590 (19 900 m^3/d)	1 070 (15 500 m^3/d)	4 670 (11 500 m^3/d)	47 230 (202 100 m^3/d)	5 900 (12 000 m^3/d)	2 500 (8 200 m^3/d)	15 880 (111 000 m^3/d, Taiho and Okuma combined)	2 090
Industrial	11 300 (31 200 m^3/d)	130 (4 800 m^3/d)	3 270 (19 800 m^3/d)	210 (7 100 m^3/d)	380 (5 500 m^3/d)	1 740 (12 000 m^3/d)[b]	17 030 (80 400 m^3/d)	7 100 (83 795 m^3/d)[b]	—	—	—
Subtotal	42 700 (118 000 m^3/d)	500 (18 000 m^3/d)	12 400 (75 000 m^3/d)	800 (27 000 m^3/d)	1 450 (21 000 m^3/d)	6 410 (23 500 m^3/d)	64 260 (282 500 m^3/d)	13 000 (95 795 m^3/d)	2 500 (8 200 m^3/d)	15 880 (111 000 m^3/d, Taiho and Okuma combined)	2 090
Total Usable	44 700	600	12 600	950	1 600	6 650	67 100	15 600	4 400	17 200	2 810
Dam Structure											
Type[c]	R	G	Main: G / Side: R	G	C: G / R	Main: G / Side: R		R	G	Main: G / Side: R	R
Height (m)	91.7	44.5	86.0 / 32.0	41.5	42.0 / 35.0	45.0 / 37.0		66.5	41.5	77.5 / 70.0	81.0
Length (m)	260	177	245 / 80	210	230.1 / 330.0	185.0 / 500.0		198	330.0	390 / 730	370
Volume (10^3 m^3)	1 622.4	73.6	414.0 / 77.7	70.0	130.0 / 440.0	72 / 991		1 050	130	530 / 2 640	1 550
Elevation of Dam Summit (m)	90.0	164.5	113.5 / 114.5	136.5	183.5 / 184.0	33.0 / 34.5		74.0	29.0	73.5 / 75.0	162.0
Construction Cost (million ¥)	1 378 (all completed projects)							510	300	950 (Taiho and Okuma)	

[a]F = flood control, N = conservation of natural river flow, W = water supply, I = industrial water, and A = agricultural water.
[b]Maximum intake for agricultural water.
[c]G = concrete gravity dam, R = rockfilled dam, and C = combined concrete gravity and rockfilled dam.

TABLE 2. Dam and Reservoir Projects Under Okinawa Prefectural Government Control

Project	Flood Control	Total River Development Project						Small-Scale Dam Development		
Dam and Reservoir	Kinjyo	Kurashiki	Zamami	Maezato	Shiramizu	Gima	Taihara	Azaka	Gakiya	Tokashiki
Catchment Area (km^2)	1.70	4.70	0.19	4.82	3.38	1.89	0.95	2.50	0.45	0.37
Reservoir Area (km^2)	0.04	0.77	0.01	0.26	0.16	0.09	0.07	0.08	0.05	0.02
Reservoir Volume (10^3 m^3)										
Total	510.0	7 100	66.0	2 300	2 150	495.0	560.0	630.0	244.0	72.5
Normal Storage	470.0	6 900	56.0	2 100	2 010	465.0	510.0	500.0	221.0	35.5
Flood Control	340.0	1 000	21.0	800	380	85.0	170.0	130.0	33.0	13.5
Usable	130.0	5 900	35.0	1 300	1 630	380.0	340.0	370.0	188.0	22.0
Dam Structure										
Type[a]	G	R	G	R	G	E	E	G	G	G
Height (m)	19.0	33.5	30.0	27.0	59.0	21.0	22.0	46.0	30.0	20.7
Length (m)	120.0	441.0	85.0	367.4	625.0	165.0	230.0	173.0	115.0	78.0
Volume (10^3 m^3)	12.8	876.0	19.0	362.0	385.0	60.0	160.0	54.0	39.0	7.9

[a]G = concrete gravity dam, R = rockfilled dam, and E = earthfilled dam.

Faced with this situation, a system for small-scale dam projects as a government subsidy program was established in 1988 with the purpose of improving small local rivers and supplying irrigation water to nearby communities. From the time of the program's establishment through 1995, 107 projects (including 96 multipurpose dam projects and 11 river improvement projects) have been carried out in 37 prefectures. In the case of dam projects where the water supply is located in the same area that the project is conducted, people welcome the dam and refer to it as "the dam by our village, of our village, and for our village" because of its great promise for contributions to the enrichment of the community.

沖縄における飲料水および地下水の水質に関する問題

山城高俊

要約

沖縄本島では，沖縄県企業局が唯一の水の卸売りを行い，処理水，未処理水を，５０００人以上の供給人口をもつ，８７の水道事業者に供給している．

飲料水源の大半はダムと河川水であるが，とりわけ，これらの水源のうち，人口の集積した地域に近い水源は，家庭や畜産（ほとんどが養豚）からの排水によって汚染されている．水道水の塩素消毒はトリハロメタンの生成につながるため，この生成を減少させるために，塩素注入量を７０％にまで減らし，さらに，試験サンプルの残留塩素を０．１ｍｇ／ｌｉｔより以下に下げるよう，取り組んでいる．その結果，本島では，活性炭処理やオゾン処理などによる，より高度の処理が必要とされるようになってきている．

宮古島や他の島では地下水が主要な飲料水源であり，肥料その他から生じる硝酸態窒素や亜硝酸態窒素は１０ｍｇ／ｌｉｔの基準値を超えつつある．これらの硝酸態，亜硝酸態窒素を取り除くため，１９９１年以来，低圧の逆浸透膜法が用いられている．また，Ｃａ硬度や全蒸発残留物の量を減らすために，ペレット法が用いられている．

海水淡水化が用いられている離島では，２－４ｍｇ／ｌｉｔにおよぶホウ素が検出され，ホウ素の基準値の０．２ｍｇ／ｌｉｔをはるかに上回っている．この近年検出されるようになってきたホウ素については，残念ながら，改善のための対策は今のところとられていない．

QUALITY PROBLEMS OF DRINKING WATER AND GROUNDWATER IN OKINAWA PREFECTURE

Takatoshi Yamashiro[1]

WATER SUPPLY IN OKINAWA PREFECTURE

The percentage of the population in Okinawa Prefecture being served by public water supply systems as of March 1996 was 99.8%, the third highest rate among the 47 prefectures in Japan. However, demand for water has been increasing year after year due to the rise in living standards and the development of tourism, along with the construction of resort facilities such as hotels and the supporting infrastructure. Thus, it has been a major task for Okinawa to develop water resources by building dams and installing seawater desalination plants. At the same time, the aim of the water administration has been to secure emergency lifelines in case of large-scale disasters such as earthquakes.

The total water demand population as of the end of March 1995 was 1 259 984. Waterworks with user groups exceeding 5000 people serviced 96.3% of this population and small-scale waterworks with user groups of 5000 or less people serviced the remaining 3.7%. As for the number of waterworks, there was one major wholesaler, 31 lesser waterworks serving 37 municipalities, and 56 small-scale waterworks serving 24 municipalities.

PRESENT SITUATION ON SOURCES FOR WATERWORKS

Surface water is the main source of water supply in the main Okinawa Island, Ishigaki Island, Kume Island, and some of the smaller islands. Groundwater is the main source in the Miyako Islands and some other islands. In the case of isolated islands which are not favored with surface or groundwater, seawater desalination plants are being introduced to supply water to the residents on a stable basis. Also, in the case of 16 isolated islands, water for daily use is being supplied by submarine water supply systems.

When judged in terms of biochemical oxygen demand (BOD), which is a typical contamination index, the quality of water used for the public supply in Okinawa Prefecture is improving due to the construction of public sewer systems and a rise in residents' consciousness of public health matters. However, the quality of water in rivers tapped for water supply has not consistently met the environmental standard denoted as Category B. Category B corresponds to water supply Class 3, in which the BOD is less than or equal to 3 mg/l.

Another problem is groundwater contamination. A highly permeable Ryukyu limestone covers the central and southern parts of Okinawa Island and is also prevalent on other islands such as Miyako, Tarama, Irabu, and Izena. Because of this high permeability, groundwater is easily contaminated by surface sources.

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The present condition of dams, rivers, and groundwater, which are the main sources of water supply, is given below.

Kin Dam

Kin Dam is located in the northern part of Okinawa Island. Recently, eutrophication has begun to take place, due to the inflows of wastewaters from both domestic and livestock sources. This has led to an increase in the trihalomethane formation potential.

Hija River

Hija River is located in the central part of Okinawa Island. The quality of its water improved up to 1986, when the environmental standard was met. However, it is now contaminated with wastewater inflows from various domestic, livestock, industrial, and other sources (Figure 1).

Tengan River

Tengan River is located in the central part of Okinawa Island. It reached its highest water quality level in 1985 and has remained at about the same level since then. The quality of water has not met the environmental standard. The main causes of contamination are inflows of wastewaters from domestic, livestock, industrial, and restaurant sources (Figure 2).

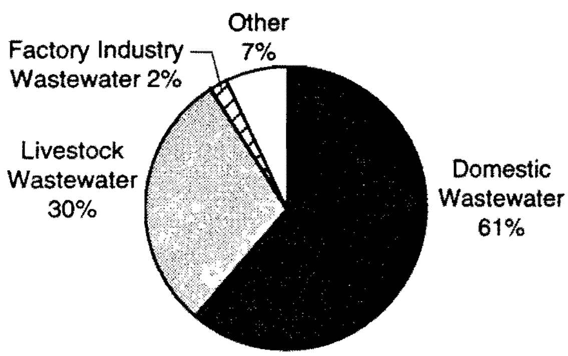

Figure 1. Causes of contamination of Hija River (1993 survey)

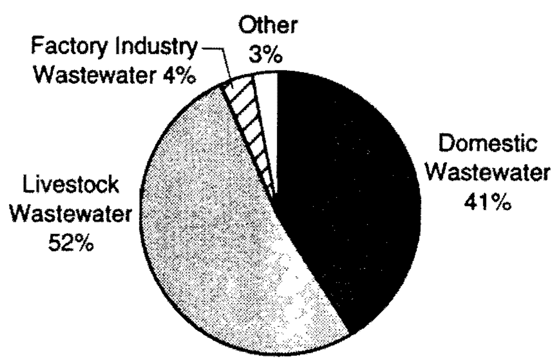

Figure 2. Causes of contamination of Tengan River (1993 survey)

Taiho River

Taiho River is located in the northern part of Okinawa Island. The quality of water in this river fell below the environmental standard in 1991 and is now showing an improving trend. In 1994 it cleared the environmental standard. The main source of contamination is the wastewater inflow from an upstream farm where as many as 15 000 pigs are being raised (Figure 3).

Groundwater

In the case of the Miyako Island, it is suspected that the groundwater may be contaminated with nitrogen by the inflows of wastewater from domestic and livestock sources and by agricultural fertilizers. The causes of nitrogen contamination are shown in Figure 4. Presently, however, there is apparently no particular problem other than hardness of potable water. In the cases of Irabu and Tarama Islands, four water quality indices are above the water quality standards: hardness, nitrate and nitrite nitrogen, chlorides, and total residue. All these are caused by miscellaneous wastewater inflows from domestic sources and by agricultural fertilizers.

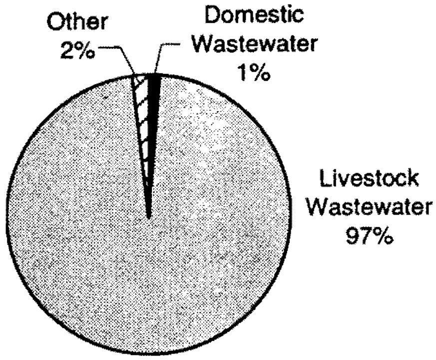

Figure 3. Causes of contamination of Taiho River (1993 survey)

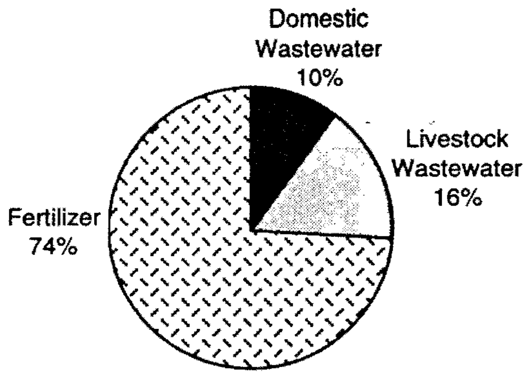

Figure 4. Causes of nitrogen contamination in groundwater of Miyako Island (1990 survey)

QUALITY OF DRINKING WATER

Recently, the dams and rivers in the central and northern parts of Okinawa Island have become so badly contaminated with wastewaters from various domestic, livestock, and industrial sources that advanced water treatments with biologically activated carbon and ozone have become necessary.

Dams and Reservoirs

Stagnant waters in reservoirs behind dams tend to increase in organic substances with the accumulation of silt and humus material. Also, in situations where villages are located upstream of the dams, the water is further contaminated as a result of the inflows of domestic and other types of wastewaters. The eutrophication of reservoirs is hastened with the growth of algae. This situation is reflected in the quality of drinking water on Zamami Island (Table 1).

TABLE 1. Zamami Island Drinking Water Quality, 1995

Parameter	Maximum Value	Average Value	Water Quality Standard
Trihalomethanes	0.18 mg/l	0.13 mg/l	0.1 mg/l or less
Chlorides (Cl^-)	285 mg/l	173 mg/l	200 mg/l or less
Total Residue	925 mg/l	486 mg/l	500 mg/l or less
Hardness (Ca, Mg)	387 mg/l	159 mg/l	300 mg/l or less

NOTE: Water quality is to be improved after 1998.

River Water Resources

Rivers in Okinawa are apt to be directly influenced by pollutants because of their relatively short distances and small flow capacities. Recently, pollution of rivers due to wastewater inflows from domestic and livestock activities has become an issue. There has been an increased awareness of the harmful effects of trihalomethanes and other contaminants in potable waters. In 1994, it was found that trihalomethanes in the treated waters at the Ishikawa Treatment Plant and the Nishihara Treatment Plant exceeded the maximum allowable limit of 0.07 mg/l or 70% of the water quality standard of 0.1 mg/l. The countermeasures adopted involve the reduction of chlorine in the treatment process. Prechlorination was replaced by interim chlorination, and the amount of chlorine additions was lowered.

Groundwater Resources

Because there are no rivers in the Miyako Islands, only groundwater found in the Ryukyu limestone is tapped to supply drinking water. Hardness in this groundwater supply is higher than that for dam and river waters.

As in the case with surface waters, it was recently found that the groundwater resources, not only in Miyako but in other groundwater islands as well, have also been contaminated by wastewaters from various domestic sources and by chemical fertilizers. As shown in Tables 2 through 6, levels of nitrates, nitrites, and chlorides exceed their respective water quality standards in the different islands. Total residue and hardness levels are also excessive.

TABLE 2. Izena Island Drinking Water Quality, 1995

Parameter	Maximum Value	Average Value	Water Quality Standard
Total Residue	836 mg/l	622 mg/l	500 mg/l or less
Hardness (Ca, Mg)	452 mg/l	361 mg/l	300 mg/l or less

NOTE: In 1996, to improve the drinking water quality, the pellet method was applied to remove calcium and reduce hardness and total residue.

TABLE 3. Tarama Island Drinking Water Quality, 1995

Parameter	Maximum Value	Average Value	Water Quality Standard
Nitrate Nitrogen + Nitrite Nitrogen (NO_3-N + NO_2-N)	11.2 mg/l	10.0 mg/l	10 mg/l or less
Chlorides (Cl^-)	316 mg/l	237 mg/l	200 mg/l or less
Total Residue	1890 mg/l	896 mg/l	500 mg/l or less
Hardness (Ca, Mg)	418 mg/l	390 mg/l	300 mg/l or less

NOTE: In 1996, the pellet method and low-pressure reverse osmosis were applied to reduce the levels of nitric and nitrous acids, hardness, and total residue.

TABLE 4. Miyako Island Drinking Water Quality, 1995

Parameter	Maximum Value	Average Value	Water Quality Standard
Hardness (Ca, Mg)	302 mg/l	290 mg/l	300 mg/l or less

NOTE: During 1997–1998, the pellet method will be applied to remove calcium and reduce hardness.

TABLE 5. Irabu Island Drinking Water Quality, 1995

Parameter	Maximum Value	Average Value	Water Quality Standard
Nitrate Nitrogen + Nitrite Nitrogen (NO_3-N + NO_2-N)	9.83 mg/l	9.25 mg/l	10 mg/l or less
Chlorides (Cl^-)	346 mg/l	258 mg/l	200 mg/l or less
Total Residue	1050 mg/l	812 mg/l	500 mg/l or less
Hardness (Ca, Mg)	359 mg/l	333 mg/l	300 mg/l or less

NOTE: After 1998, the low-pressure reverse osmosis treatment will be applied to reduce the levels of nitric and nitrous acids, chlorides, hardness, and total residue.

TABLE 6. Nago City, Okinawa Island, Raw Water Quality, 1995

Parameter	Maximum Value	Average Value	Water Quality Standard
Total Residue	1890 mg/l	896 mg/l	500 mg/l or less
Hardness (Ca, Mg)	224 mg/l	208 mg/l	300 mg/l or less

NOTE: In 1997, the pellet method was applied to remove calcium and reduce total residue and hardness.

Seawater Desalination

In remote small islands like North and South Daito Islands where there are no mountains and rivers, people have depended on capturing rainwater in reservoirs for their water supply. However, because this is not a secure and stable source of water and because the quality is not satisfactory, small-scale seawater desalination plants have been installed. But seawater is high in boron; 2 to 4 mg/l have been detected in the potable water supplies (the boron monitor index is 0.2 mg/l). We have not yet found a satisfactory method for reducing the boron level, and this is an urgent need for our small-scale seawater desalination plants in remote islands.

COUNTER MEASURES FOR CONTAMINATION PREVENTION AND SUBJECTS FOR FUTURE CONSIDERATION

With the recent increase in water contamination due to inflows of wastewater originating from various sources (domestic, livestock, industrial, and agricultural sources), the presence of harmful toxins such as trihalomethanes and nitrates in potable supplies has become a pressing issue. In 1994, a law was enacted to promote the combination of domestic wastewaters from all sources (flush toilets, showers and bathtubs, sinks, and laundry machines) for efficient treatment and disposal through sewage treatment plants in urban areas and septic tanks in rural areas. The aim was to secure—through integration, consolidation and other drastic means—the quality of water resources for drinking water supplies. Based on this law, the Okinawa Prefecture Enterprise Bureau submitted a request to the governor in July 1995 for the purpose of securing the quality of water in the Kin Dam and the basins of the Taiho River and Tengan River. A framework plan is to be developed so that projects can be carried out in a systematic manner. The plan will promote the improvement of sewer systems, combined filtration tanks, and wastewater disposal facilities in agricultural villages to reduce the potentials for harmful contamination of water resources. The list of countermeasures to be taken and subjects to be considered follow.

Countermeasures to Prevent Contamination

The countermeasures to prevent contamination are as follows:

1. Livestock solid waste tanks shall be maintained adequately to prevent outflow of solids.
2. Wastewaters from livestock barns shall be processed to reduce the volume of liquid wastes discharged into rivers.
3. Efforts shall be exerted to reuse the solids as fertilizer and to restore the fertility of farm lands.
4. Health centers shall provide guidance on the adequate maintenance of solid waste facilities to prevent outflows during rains.
5. Dealing with trihalomethanes shall be effected through the following projects scheduled to begin in 1997:
    - Installation of a combined purification tank and drainage facility for agricultural villages in the Tengan River basin and the Kin Dam area.
    - Promotion of the installation of drainage facilities in the Tengan River basin.
    - Installation of livestock wastewater treatment and composting facilities in the Taiho River and Tengan River basins and the Kin Dam area.
6. For the purpose of improving the quality of groundwater in Izena Island, Miyako Islands, and other areas, the pellet method and low-pressure reverse osmosis treatment shall be applied (beginning in 1996) to reduce nitrates, nitrites, chlorides, hardness, and total residue.

Subjects for Future Consideration

In order to introduce disposal facilities for domestic and livestock wastewater which otherwise would tend to flow into the dams and rivers and to actively carry out water quality conservation projects, the Okinawa Prefectural Promotion Plan requires the cooperation of the municipalities and other local bodies located near basins. In the case of the Miyako Island, where the source of potable water is limited to groundwater, it is necessary to minimize the use of chemical fertilizers. For isolated islands like Zamami and others that are not favored with water resources (in terms of both quantity and quality) and that do not have alternative sources readily available, it is necessary to consider the introduction of seawater desalination plants. The following are subjects for consideration:

1. Miscellaneous wastewater produced from domestic sources within a sewer service area should be discharged into the sewer system. For non-sewered areas, wastewaters should be disposed by the combined filtration and disposal method, subject to the cooperation of the residents within the basin area.

2. As for the disposal of livestock wastes, it is essential to install composting systems and then to return the composted material to farmlands within and outside the basin area. It is also necessary to obtain the cooperation of the municipalities and the local people engaged in agricultural and livestock activities.

3. In order to promote water quality preservation projects, the procurement of an adequate budget is essential.

4. In the case of isolated islands where seawater desalination is being introduced and where water quality improvement projects must rely on the pellet method, low-pressure reverse osmosis treatment, and other techniques, the high costs of producing potable water cannot be fully recovered through revenues from water rates.

沖縄における新・海水淡水化施設について

大城盛吉

要約

沖縄県では，これまで２０年以上にわたって海水淡水化技術の経験を有する．１９７４年以来，離島において，５基の小規模海水淡水化施設が建設され，各々２４０から４００立方メートル／日の供給量をもち，飲料水源として現在も稼動中である．

本島では，これまで河川やダムを水源としてきたが，渇水期においても安定した水供給を行うために，新海水淡水化施設の建設に着手した．この施設は逆浸透膜技術を用いており，現在，日本国内で稼動している施設の中でもっとも規模が大きく，また今日，世界中で稼動している施設の内で，第５位の規模を誇る．この施設で用いられている膜は螺旋タイプであり，芳香ポリアミド化合膜を用いている．処理能力は淡水４万立方メートル／日の供給量として計画され，海水１０万立方メートル／日を処理して得られるため，回収率は４０％である．１９９６年に１万立方メートル／日の供給から開始し，１９９７年３月には最大の供給量を達成する．

海水は海底集水システムによって集められ，また塩水廃液は，海岸から沖合い２００メートルのところに設置された水中の塔から排出される．その塔に取り付けられた１６基の拡散ノズルを通じて上方向４５度の角度で排出される．施設の全費用はおおよそ３５０億円（約３億ドル）と推計され，８５％は国の補助金である．

NEW DESALINATION PLANT IN OKINAWA

Seikichi Oshiro[1]

Geographically, Okinawa Prefecture is located in Japan's only subtropical region. It is warm all year round, with an average annual temperature of 22°C. Okinawa Prefecture is an archipelago of 160 islets and islands, 50 of which are inhabited. Among the many islands, Okinawa, Ishigaki, and Miyako are relatively large, with Okinawa Island being by far the largest. It has a long and slender shape, measuring about 130 km in length from north to south and 4 to 8 km wide. The population of Okinawa Prefecture is approximately 1.26 million, with about 90% of the people living on the island of Okinawa. Accordingly, the island is the most heavily populated, and water consumption there is the highest.

Okinawa Island is flat in the southern and central parts where the area is densely populated, and mountainous in the northern part where the area is less populated. Consonant with the nature of the island, most of the water supply is developed in the northern part, yet most of the water is consumed in the central and southern parts. This distributional imbalance between water supply and consumption is one of the distinct aspects of water management in Okinawa Island.

WATER SUPPLY

Okinawa waterworks rely heavily on seasonal rainfalls during May–June and seasonal typhoons later in the year. The amount of rainwater obtained during these seasons has a lot of influence on water services in Okinawa. The sources of water supply for the island consist basically of dams and reservoirs (60%), flowing rivers (28%), underground water (11%), and seawater desalination facilities (less than 1%).

An islandwide water supply system is operated by the Okinawa Prefectural Enterprise Bureau. As the main purveyor of water, the bureau's role is developer of water resources and supplier of potable water to the people. The bureau draws about 440 000 m^3/d of raw water for treatment and then supplies potable water to 30 of the 34 municipalities on the island.

Since the reversion of Okinawa to Japan in 1972, a major effort was jointly undertaken by the national and prefectural governments to develop water resources on Okinawa Island. A number of dams and rivers have been developed under a plan for the promotion and development of Okinawa Prefecture. So far, seven multipurpose dams and thirteen water intake pump stations have been constructed and put into operation.

Despite these water resources development projects to increase the water supply, frequent water shortages have been experienced on Okinawa Island during the past several years. One reason for these recurring shortages is unstable river flows. Okinawa Island depends on rivers for almost one-third of its water supply, but the unstable flows make rivers unreliable sources.

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Rivers on Okinawa Island are all Class 2 or smaller, as categorized under the National River Law. They are essentially island streams with small catchment areas, as well as channels that are short and narrow and have steep gradients. Therefore, during dry spells the river water supply diminishes.

Another reason for shortages is the ever-increasing demand for water. Its consumption has been continuously increasing with the growth of the population, economic development and prosperity, and tourist and resort developments. The increasing water demand is expected to continue.

For these reasons, the Okinawa Prefectural Enterprise Bureau has begun large-scale desalination of seawater as a means of supplementing traditional land-based water sources.

SEAWATER DESALINATION

Seawater desalination in Okinawa Prefecture actually began in 1974 on a small remote island (Minami Daito) located far to the east of Okinawa Island. Since then, the technology has been introduced successfully on other small islands. At present, five small islands use seawater desalination plants to secure their water supply. These desalination plants are, however, very small-scale facilities, with capacities ranging from 240 to 400 m^3/d. Nevertheless, these plants are the only important source of secure water supply for the people living on these small islands.

Compared to these small-scale plants, the new desalination plant being built on Okinawa Island is, by far, a larger-scale operation that is almost 100 times greater in capacity. The total plant capacity is designed to be 40 000 m^3/d. The total construction cost of the plant is estimated at around 35 billion yen, of which 85% has been subsidized by the national government.

The chronology for development of this large-scale seawater desalination facility in Okinawa is as follows:

- 1977–1986 Japan Ministry of Welfare conducts a comprehensive study on seawater desalination for Okinawa Island.
- 1988 Okinawa Prefectural Enterprise Bureau obtains authorization from the Ministry of Welfare to install a seawater desalination plant.
- 1989 Basic plan for construction of the plant is completed by the bureau.
- 1990–1991 A 15-member committee is organized to study a phase-in plan for the plant and any environmental impact. The committee members include university professors, officials from national and prefectural governments, and officers of local companies.
- 1992 The design of the desalination plant is made, based on proposals from committee members.
- 1993 Construction of desalination plant begins.
- 1996 First stage of construction is completed, and partial plant operations begin at freshwater production rate of 10 000 m^3/d. Project completion date is set for March 1997.

At present, reverse osmosis is considered the most economical method for producing freshwater from seawater. To produce 40 000 m^3/d of freshwater, 100 000 m^3/d of seawater is needed. In other words, 40% of the total volume of seawater is changed to freshwater.

Figure 1 illustrates the principles of osmosis and reverse osmosis as applied in the desalination of seawater. When freshwater is placed in one side of a container separated by a semipermeable membrane and seawater is placed in the other side, the concentrations of both solutions will tend to equalize. A natural flow of pure water will pass through the semipermeable membrane from the freshwater side to the seawater side. This is called the "osmosis phenomenon." The flow of pure water will stop when a certain difference between the levels of both solutions is achieved. This difference in the levels of both solutions is called the "osmotic pressure" of seawater. (The osmotic pressure of seawater is about 25 kg/cm^2.) When a higher than the osmotic pressure is applied to the seawater, pure water contained in the seawater is pushed back through the semipermeable membrane to the freshwater side. This principle is called "reverse osmosis."

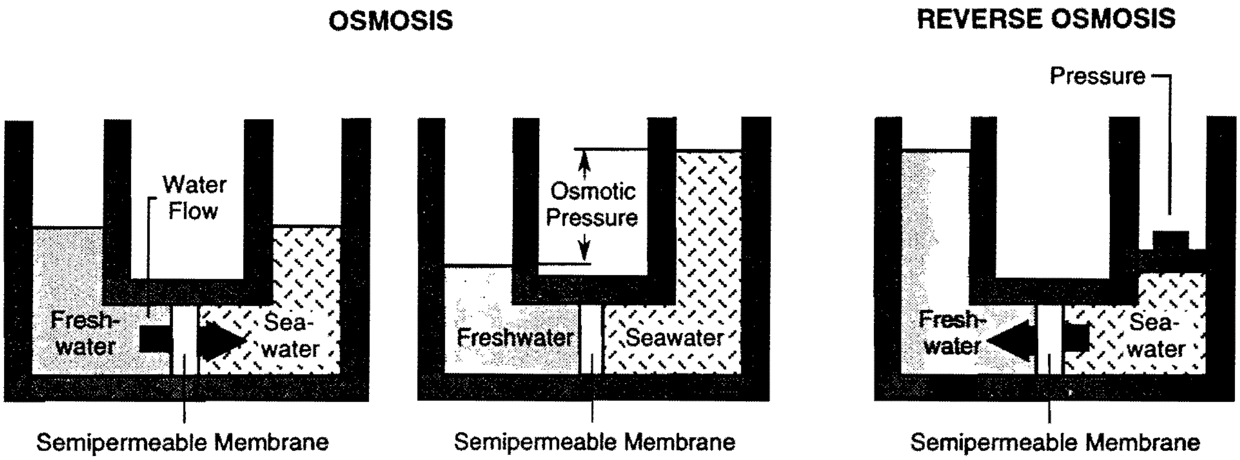

Figure 1. Desalination of seawater using principles of osmosis and reverse osmosis

Figure 2 is an illustration of an element of a desalination module which utilizes the reverse osmosis method. Highly pressurized seawater is fed through the left side of the element, pure water is collected in the center tube, and brine comes out on the right side.

Figure 3 is a schematic of the seawater desalination process in the overall facilities. The desalination plant basically consists of five facilities. The first is a seawater intake facility consisting of an intake tower, an intake pipeline, and a sand-settling basin. The second is an adjusting facility consisting of primary and secondary filters. The third is a desalination module facility consisting of high-pressure pumps, reverse osmosis membrane units, and energy-recovery turbines. The fourth is a brine-discharging facility consisting of a discharging pipeline and a tower with diffusing nozzles. The fifth is a condensing and dehydration facility consisting of a condensing basin and a dehydration unit.

The process of desalination begins with the natural flow of raw seawater into the sand-settling basin where sodium hypochlorite is added for sterilization. The sterilized seawater is passed through the primary and secondary filters. The clean seawater is then treated with sodium

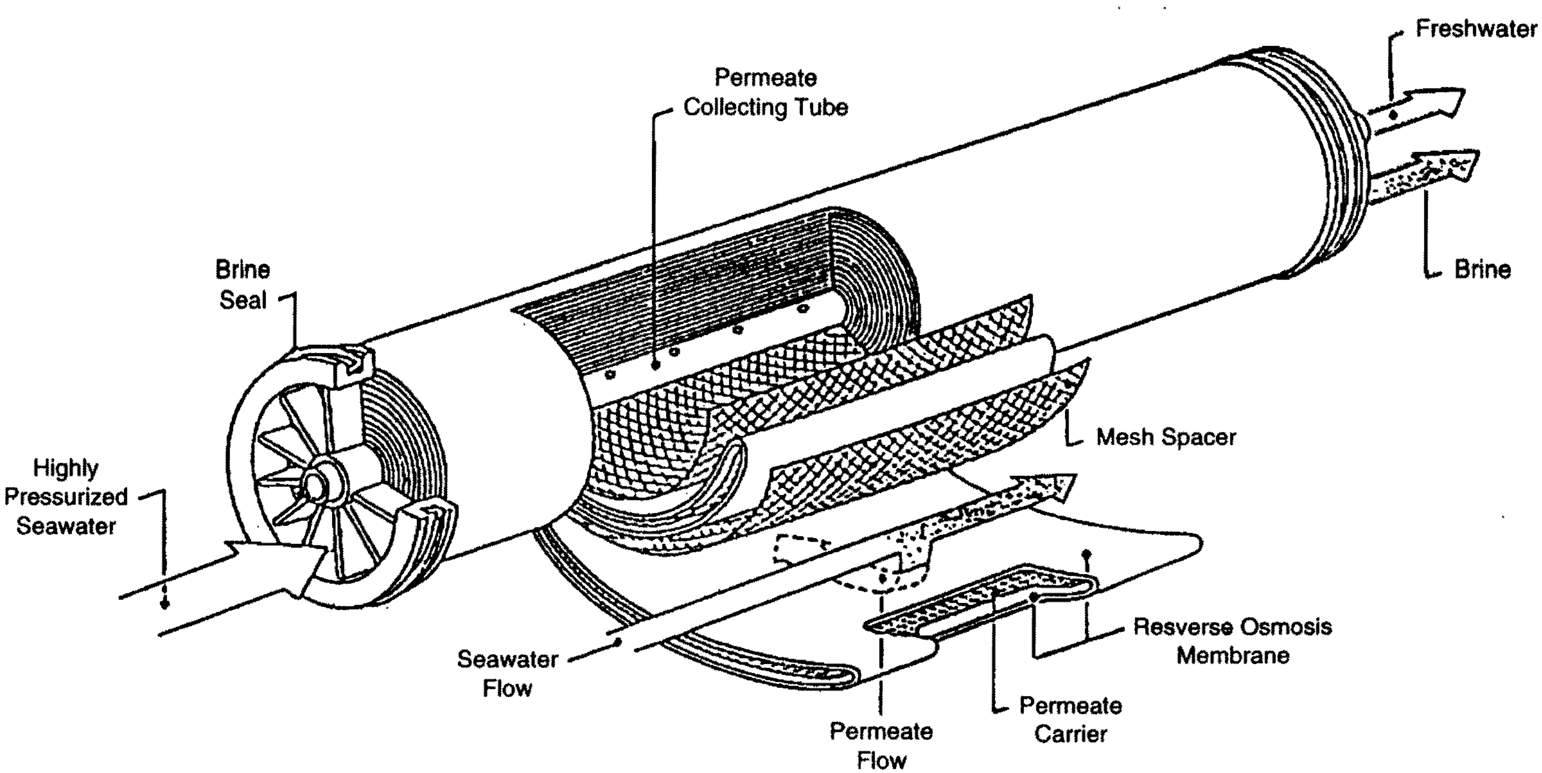

Figure 2. Reverse osmosis membrane element

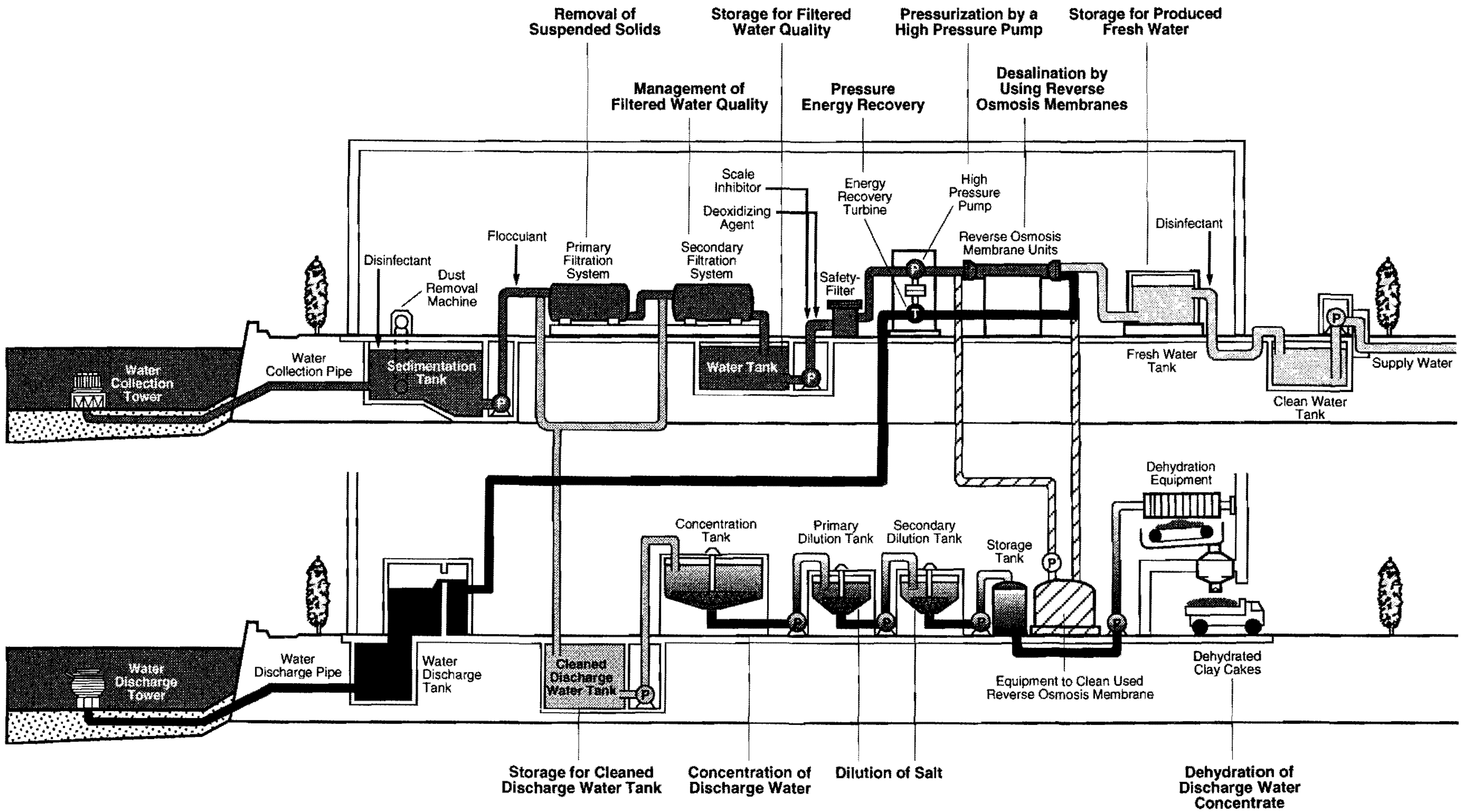

Figure 3. Schematic of the desalination process

NOTE: This schematic is based on a color version published in a brochure entitled "Seawater Desalination Plant: Abundant Water From The Beautiful Ocean" (published by the Enterprise Bureau, Okinawa Prefecture, March 1, 1996, pp. 10–11). That version shows the desalination process more clearly with the use of color.

bisulfite to neutralize the remaining chlorine, and acid is added to control the pH before it is fed into the desalination module where pressure of between 60 and 65 kg/cm^2 is applied.

After desalination, the desalted water is usually treated with ash or caustic soda for pH control and adjusted for taste with the addition of some minerals. In our Okinawa plant, however, none of these treatments is necessary because the desalted water is directly mixed into the existing potable water supply from land sources.

To protect the environment, we have adopted two additional measures. One is a diffusion method for discharging the brine into the sea, and the other is the recovery of sludge produced after filtration of the raw seawater by dehydration. The dehydrated sludge can then be used for land reclamation instead of being dumped back into the ocean as slurry.

Figure 4 illustrates an idealized plume of the brine being diffused in seawater. The brine is discharged through 16 diffuser nozzles mounted at a 45° angle on a discharging tower located about 200 m offshore where the tidal current is present.

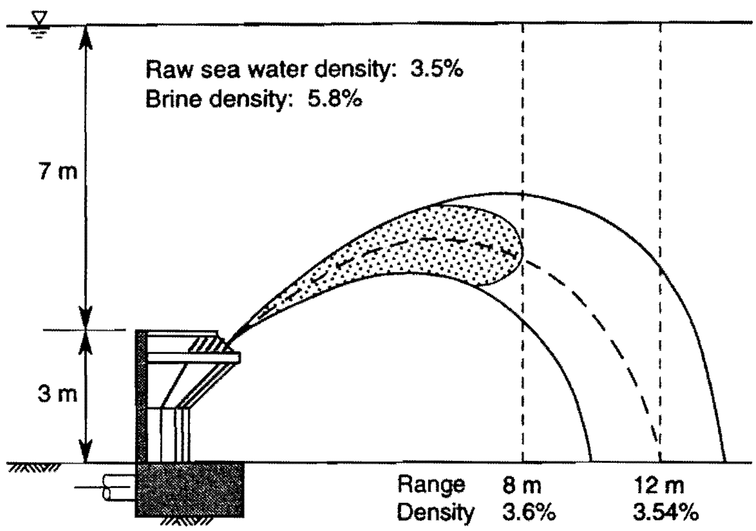

Figure 4. Idealized plume of brine being diffused in seawater

Some advantages of our seawater desalination project in Okinawa are listed below:

1. Potable water can be obtained from a practically limitless quantity of seawater which, unlike rainfall, is basically unaffected by adverse weather conditions.
2. A relatively small land area is required for the plant.
3. Completion of plant construction can be scheduled according to needs.
4. Location of the plant is near the service area.

Finally, as with most new projects, the operation of a large-scale desalination plant presents a number of new challenges for the future. A list of considerations follows:

1. An optimum plant-operating pattern must be established, taking into account the high operating and maintenance costs of running the desalination facilities. Energy requirements, in particular, are high.
2. An environmental monitoring program must be put in place to protect against degradation of the environment.
3. Effective countermeasures against corrosion of the installations must be established.
4. A program must be designed to train technicians to handle the fully automated facilities with computers.

地下ダム：建設と応用

デイビッド　ヤン

要約

この報告では，ＳＭＷ (Soil Mix Wall)法，すなわち，地下水を制御するために，３軸オーガを用いて，その場で厚さ２２インチのソイルセメント壁を作るミキシング技術を説明する．これらの穴を掘抜くオーガによって，１００メートルの深さまでグラウトを注入することができ，また，コンピューターによって，正確に列をなして掘れるように厳密に制御される．

この技術を説明するために，日本での建設事例を紹介する．

試験ダムとして瀬戸内海の島で中島地下ダムが建設された．この地下ダムは，８８メートルの幅をもち，２万７千立法メートルの貯水容量を持つ．また宮古島の砂川地下ダムは，これよりも大きな施設で，１８５３メートルの幅をもち，９５０万立法メートルの貯水量をもつ．

長期に渡る取水試験の結果，これらの地下ダムの建設によって，灌漑用の地下水を建設前より豊富に取水でき，また塩水の侵入を防ぐことができることもわかった．

砂川地下ダムについては，技術移転を目的として，建設にかかわる紹介用のためのビデオテープが用意されている．これは，宮古島で先駆的に行われた地下水を制御するための技術として，徐々に，国際的にも認知され始めているこの比較的新しい技術を，視覚的に紹介するための優れた資料である．

SUBSURFACE DAMS: CONSTRUCTION AND APPLICATIONS

David S. Yang[1]

Abstract

A subsurface dam is a facility consisting mainly of a cutoff wall installed in highly permeable strata to store groundwater and to prevent the intrusion of saltwater. The Soil Mix Wall (SMW) method is an in-situ soil mixing technology that mixes soil with cement grout using triple-axle augers to produce subsurface soil-cement walls for groundwater control. Two case examples are presented to illustrate the construction and applications of subsurface dams installed by in-situ soil mixing technology.

Nakajima Subsurface Dam—an 88-m-long test dam constructed on Nakajima island in the Seto inland Sea of Japan. The dam site is located 200 m from the coastline of a valley plain in the southeast part of the island. The alluvium at the site has a maximum thickness of 26 m and was used as the storage strata. The low-permeable bedrock underlying the alluvium served as a bottom seal of the subsurface storage area. The SMW method was selected for the installation of a soil-cement cutoff wall for use as the subsurface dam. The soil-cement has a 28-day unconfined compressive strength of 5 kg/cm^2 and a maximum coefficient of permeability of 1×10^{-6} cm/s. The storage capacity of the subsurface reservoir is 27×10^3 m^3.

Pumping tests were performed (1) to evaluate the effectiveness of subsurface dams for converting alluvial valleys into subsurface storage strata, (2) to study the methods of monitoring groundwater quality, and (3) to establish pumping and management criteria for a subsurface dam. The long-term pumping tests proved that the subsurface dam enables the pumping of additional groundwater and also prevents saltwater intrusion.

Sunagawa Subsurface Dam—a 1853-m-long dam installed 65 m into the Ryukyu limestone and keyed into the Shimajiri Mudstone. The dam site is on Miyako Island, Okinawa, Japan. The subsurface dam was designed to store groundwater in the highly permeable, porous limestone strata during the rainy season and to supply water for irrigation during the dry season. A single-shaft rock auger was used to predrill the limestone. Triple-auger SMW equipment was then used to produce soil-cement panels to form an SMW wall for use as a subsurface dam. The SMW wall has a strength of 10 kg/cm^2 and a maximum permeability of 1×10^{-6} cm/s. The storage capacity of the subsurface reservoir is 9.5×10^6 m^3.

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土地の制約のある熱帯条件下での養豚廃液処理システムについて

P．Y．ヤン

要約

ハワイの動物からのし尿は，州の人口からもたらされる有機物質の2倍の量である．家畜のし尿は，ハワイのみならず，沖縄の主要な汚染源でもある．

過去１０年以上にわたり，著者はハワイ大学生物システム工学研究室で，養豚廃液の様々な生物処理の方法に関する研究を行ってきた．一連の研究の結果として，さまざまな課題にこたえる排水管理システムを提案し，設計する上での重要な知見を提供してきた．このシステムの特徴は，処理水もスラッジも両者とも再利用でき，システムから発生するメタンガスからエネルギーを生産し，しかも社会にとって最小の費用で環境基準に合致できるなど，さまざまな利点を有するものである．

家畜のし尿は，熱帯・亜熱帯に位置する多くの島嶼がかかえる共通の課題である．この種のシステムの研究が深められるとともに，数々の利点があり，また資源の保全ができる養豚業のクリーンプロダクション技術として，多くの地域への技術移転が望まれる．

SWINE WASTE TREATMENT SYSTEMS FOR LAND-LIMITED AND TROPICAL CONDITIONS

P. Y. Yang[1]

Currently, about 4.5×10^6 lb (2×10^6 kg) of animal waste is generated daily in Hawaii. This is approximately equal to two times the organic waste generated by the human population in Hawaii. Because of the rising concern for environmental protection, the impact of animal waste has become a serious problem. For instance, on the island of Oahu, Hawaii, the more than 900 tons of manure produced each day could pollute the island's freshwater and turn the bays and coastal waters into polluted areas which would be unsuitable for swimming, fishing, and tourism activities. Added to this is the effect of methane emission. The United States Environmental Protection Agency has been aware of the huge amount of uncontrolled methane emission from livestock waste. Because a gram of methane can absorb about 70 times as much infrared radiation as a gram of carbon dioxide, methane emission significantly contributes to global warming from the greenhouse effect. Thus, the controlled treatment of livestock waste, in order to prevent the release of the untreated waste and methane gas into the environment, is required.

In 1992, the number of pigs in Hawaii was about 35 000, averaging 352 animals per farm operated by small producers. About 60% of these pig producers are located on Oahu, which is the most populated and land-limited island in Hawaii. For the past 20 years, the anaerobic lagoon system has been commonly used for the treatment of pig waste. However, there are many problems with using this system, including its limited capacity due to inadequate design, odor emission, requirement of sludge removal and final disposal of the effluent, and the possibility of letting the anaerobic lagoon become a mosquito habitat.

State and federal agencies are establishing and enforcing more stringent regulations on the disposal of animal wastes. The future of livestock and poultry production in Hawaii depends on the successful development of a cost-effective and environmentally sound management system for treatment of animal wastes.

The Department of Biosystems Engineering at the University of Hawaii has conducted animal waste management research for the past 20 years. Cost-effective and environmentally sound treatment alternatives for both highly concentrated and diluted animal wastes (including swine and poultry wastes) were successfully developed in the laboratory and in the field (pilot scale). All studies were influenced by the unique environmental, social, and economic conditions in Hawaii, such as the high cost of land, high environmental standards, and the subtropical/tropical condition.

Swine production in subtropical and tropical regions is considered important as an agricultural production system. Many biotreatment alternatives for swine wastes, based on the ways or methods of collecting and handling wastes, have been reported. The composting process for solid wastes and the anaerobic treatment of wastewater from the swine production system have been investigated. The disadvantages associated with traditional anaerobic treatment systems for moderate land-limited areas are the requirement of large volumes of digested effluent for handling and treatment and the

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lack of appropriate treatment alternatives for flushing wastewater after the scraping/separation of swine solid wastes and anaerobically treated swine wastewater.

For the past 20 years, the University of Hawaii has conducted studies on the biotreatment of animal wastewater. The studies covered the integrated anaerobic and aerobic treatment of raw swine wastewater (Yang and Nagano 1984), anaerobic treatment of concentrated swine waste with sludge recycling (Yang and Wong 1983; Yang and Nagano 1985b), algal-biomass treatment of supernatant of settled raw and anaerobically digested swine wastewater (Yang and Nagano 1985a), anaerobic treatment of diluted raw pig wastewater (Yang and Chou 1985; Yang and Moengangongo 1987), sequential batch treatment of diluted raw pig wastewater (Yang and Koba 1988), hybrid anaerobic treatment of poultry waste (Yang et al. 1989), modified two-stage anaerobic treatment with effluent recycling (Yamamoto 1992), development of a small-farm wastewater treatment plant (Yang et al. 1993a), development of a swine waste package biotreatment plant (Yang et al. 1993b), land-limited and energy-saving treatment system for diluted swine wastewater (Yang and Chen 1994), investigation of a prototype of swine waste treatment system in Hawaii (Yang et al. 1997), and sequential anaerobic treatment of concentrated swine waste (Kuroshima and Yang 1995).

Anaerobic treatment of swine wastewater has potential for success in tropical regions because of its bioenergy production and low energy input for the operation compared to the aerobic treatment process. In the 1970s, the anaerobic treatment process was investigated extensively for the treatment of combined wastewater (without solid-liquid separation) which required a bigger reactor volume. Eventually, it will not be economically sound, especially for the flushing system practiced in most tropical regions. Therefore, separate studies of concentrated and diluted swine wastewater were conducted at the University of Hawaii during the past 20 years. Also, the integration of these two separate processes was investigated in an actual field operation (Yang and Nagano 1984; Yang et al. 1997). Evaluations were conducted on process performance, operational problems, and economic aspects of the field study (Yang et al. 1997).

CONCENTRATED SWINE WASTE TREATMENTS

Anaerobic Process with Sludge Recycling

The anaerobic treatment process with sludge recycling was investigated at both the laboratory and field scales. The 20-liter laboratory-scale process is shown in Figure 1 (Yang and Wong 1983) and

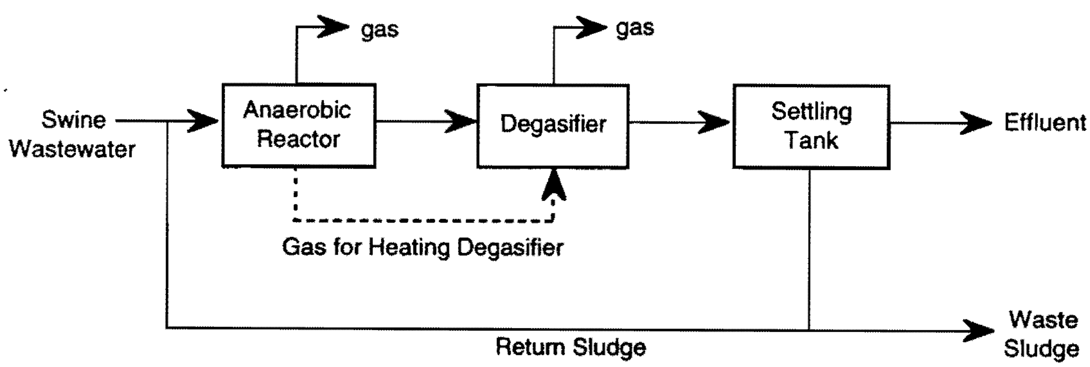

Figure 1. Anaerobic process with sludge recycling for treatment of swine wastewater (after Yang and Wong 1983)

the 20-m^3 field-scale process in Figure 2 (Yang and Nagano 1984, 1985b). It was found that anaerobic treatment of swine waste with recycling of digested sludge provides an improved and stable process. At a temperature of 24° to 26°C and a TVS loading rate of about 3.0 g/l/d, both operations achieved a biogas production rate of about 1.0 l/l/d (CH_4 content of 67% to 73%) and gas yield of 0.35 to 0.38 liter per gram of TVS added. However, under ideal operation at the laboratory scale, the biogas production rate of 2 l/l/d (74% methane gas) and gas yield of 0.42 liter per gram of TVS added could be achieved at a TVS loading rate of 4 g/l/d. The ideal or recommended design and operational criteria for the anaerobic treatment of swine wastewater with sludge recycling are as follows:

- Temperature: 30°C
- Recycled sludge to influent flow rate ratio: 0.25 to 0.30
- Recycled sludge to digested effluent TVS ratio: 2.0 to 3.0
- TVS loading rate: 4 g/l/d
- Feeding frequency: 3 times a week
- Degasification temperature of digested sludge: 50°C
- Settling time for heated sludge recycling: 5 hours
- TVS contents in the feeding: 25 g/l

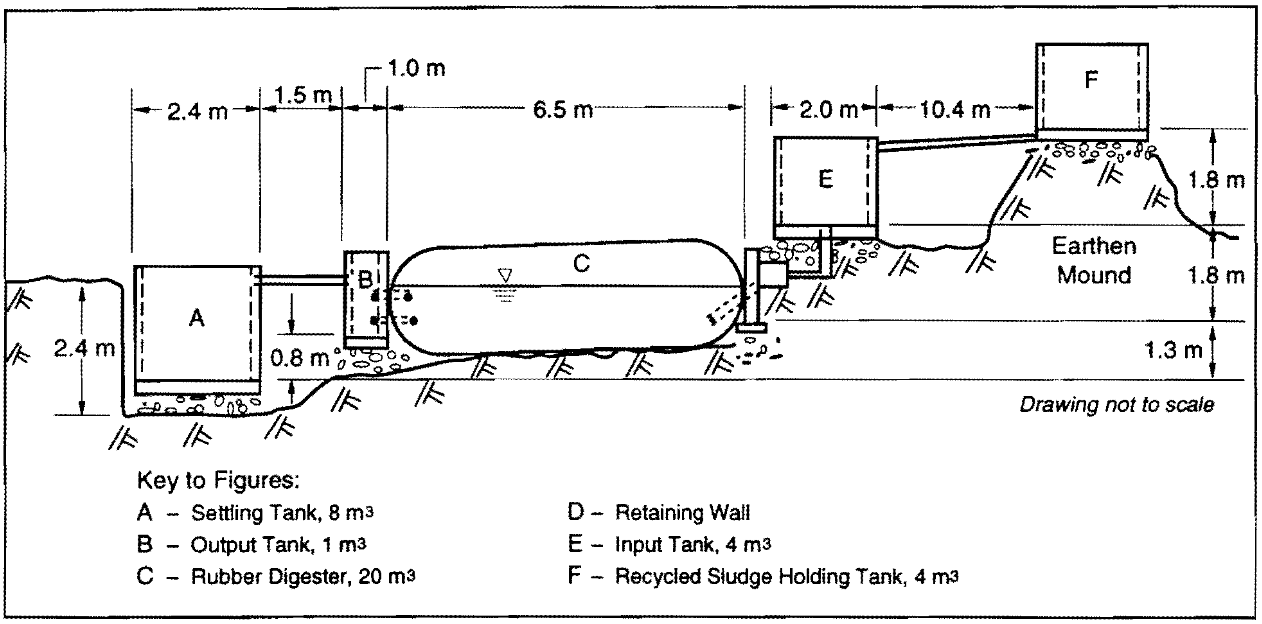

Figure 2. Schematic (field scale) showing establishment of gravity flow for input and output of anaerobic digestion process with sludge recycling (after Yang and Nagano 1985b)

Modified Two-Stage Anaerobic Treatment Process with Effluent Recycling

A modified two-stage anaerobic treatment process with partial effluent recycling was investigated (Yamamoto 1992) (Figure 3). At an initial TVS concentration of 90 g/l, a TVS loading rate of 6.0 g/l/d, recycled sludge to influent flow rate ratio of 1:1, and a temperature of 30°C, the biogas production rate was 3.0 l/l/d (70% of CH_4) and the gas yield was 0.5 liter per gram of TVS added. An economic evaluation indicated that for a pig farm to attain a net present value of zero, 450 animals are required.

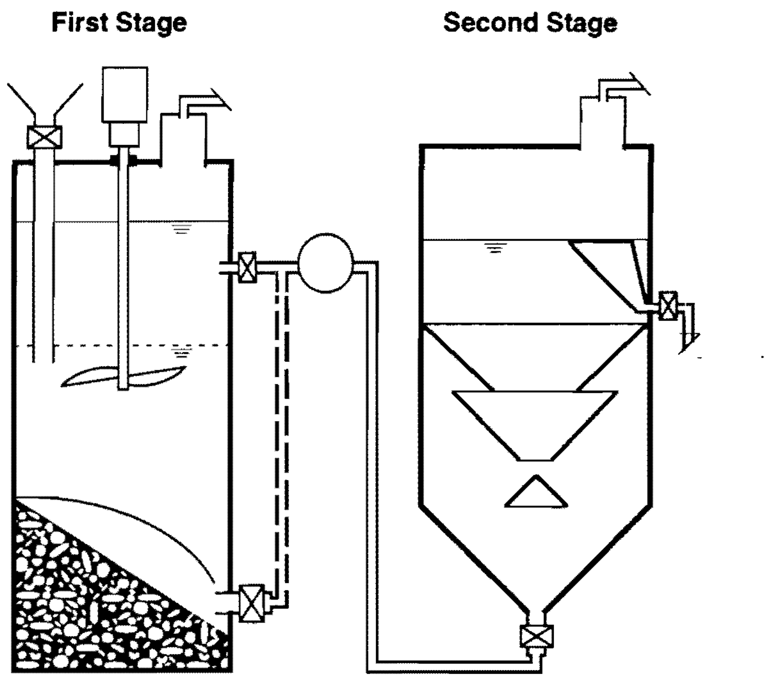

Figure 3. Schematic of modified two-stage anaerobic digester with partial effluent recycling (cross sectional view) (after Yamamoto 1992)

Sequential Anaerobic Treatment Process

Sequential anaerobic treatment of highly concentrated swine waste was investigated (Kuroshima and Yang 1995) (Figure 4). At a TVS loading rate of about 3.0 g/l/d, an initial TS concentration in the influent of 8% to 10%, and a temperature of 30°C, the biogas production rate was 1.75 l/l/d (50% CH_4) and the gas yield was 0.58 liter per gram of TVS added. The system combines a series

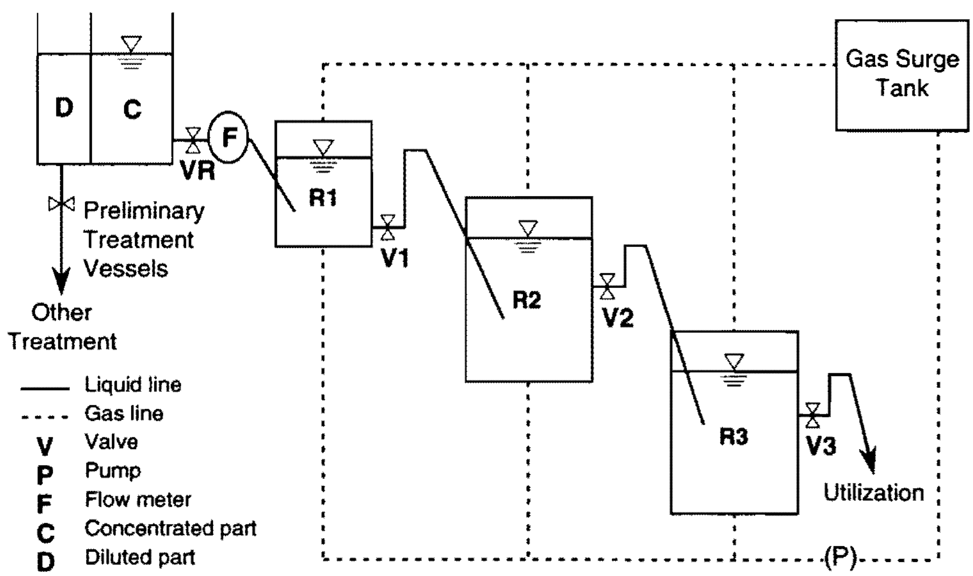

Figure 4. Schematic of sequential anaerobic process for swine waste treatment (after Kuroshima and Yang 1995)

of processes involving mixing, homogenization, biological reaction, and final stabilization of concentrated swine waste. This allows for simpler construction and ease of operation and maintenance. The estimated wastewater treatment cost of $3.76/pig/year for a 300-head farm is appropriate for small producers in tropical areas.

Summary of Treatment Alternatives

The overall process performance of anaerobic treatment of concentrated swine wastewater is summarized in Table 1.

TABLE 1. Process Performance of Various Treatment Alternatives for Concentrated Swine Wastewater in Hawaii

Treatment Alternatives	TVS Loading Rate (g/l/d)	Temperature (°C)	Average TVS Removal Efficiency (%)	Average Methane Gas Production Rate (l/l/d)
Anaerobic Process with Sludge Recycling (Lab Data)	4.0	30	—	0.7
Anaerobic Process with Sludge Recycling (Field Data)	4.2	26 ± 2	—	1.03
Modified Two-Stage Anaerobic Process with Partial Effluent Recycling	3.5 7.3	30 30	59 46	1.18 2.25
Sequential Anaerobic Process	2.95	30	70	0.88

A 120-m^3 algal-biomass raceway system (Figure 5) to treat the supernatant of raw settled and anaerobically digested swine wastewater was investigated (Yang and Nagano 1985a). This treatment can effectively remove both soluble COD (94%) and NH_4^+-N (98%) contained in the supernatant of settled raw manure and anaerobically digested manure with a COD ratio of 25, if the ratio of oxygen input to oxygen required is maintained at about 0.67 and the unit is operated at a SCOD loading rate of 0.1 g/l/d. At this loading rate, the energy consumption is 0.49 kWh per kilogram of BOD_5 removed and the area requirement is 0.09 hectare for a 1000-pig operation. Possible nitrification can occur when the ratio of oxygen input to oxygen required is above 0.67. The algal-biomass raceway system provides better land utilization and lower energy input than other aerobic stabilization processes. Thus, it is considered to be especially suited for application in tropical areas where land and fuel are costly.

Treatment Using Horizontal-Baffled Anaerobic Reactor

A horizontal-baffled anaerobic reactor with a liquid volume of 20 liters (Figure 6) was tested at 30°C for the treatment of supernatant of settled swine wastewater with a TVS concentration under 2 g/l (Yang and Chou 1985). With this system, a maximum TCOD removal efficiency rate of 81%

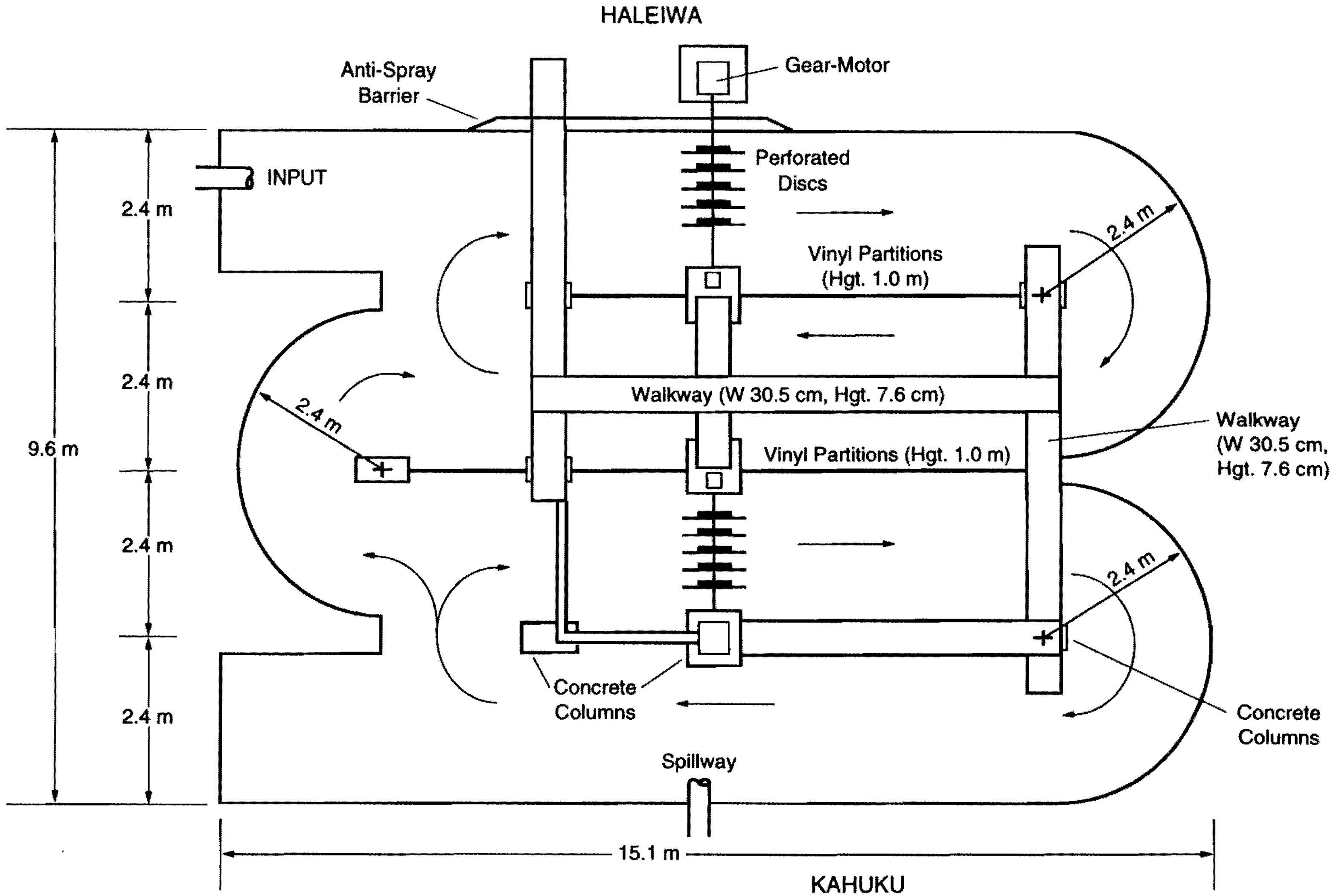

Figure 5. Diagram of algal-biomass raceway system for treatment of swine wastewater (after Yang and Nagano 1985a)

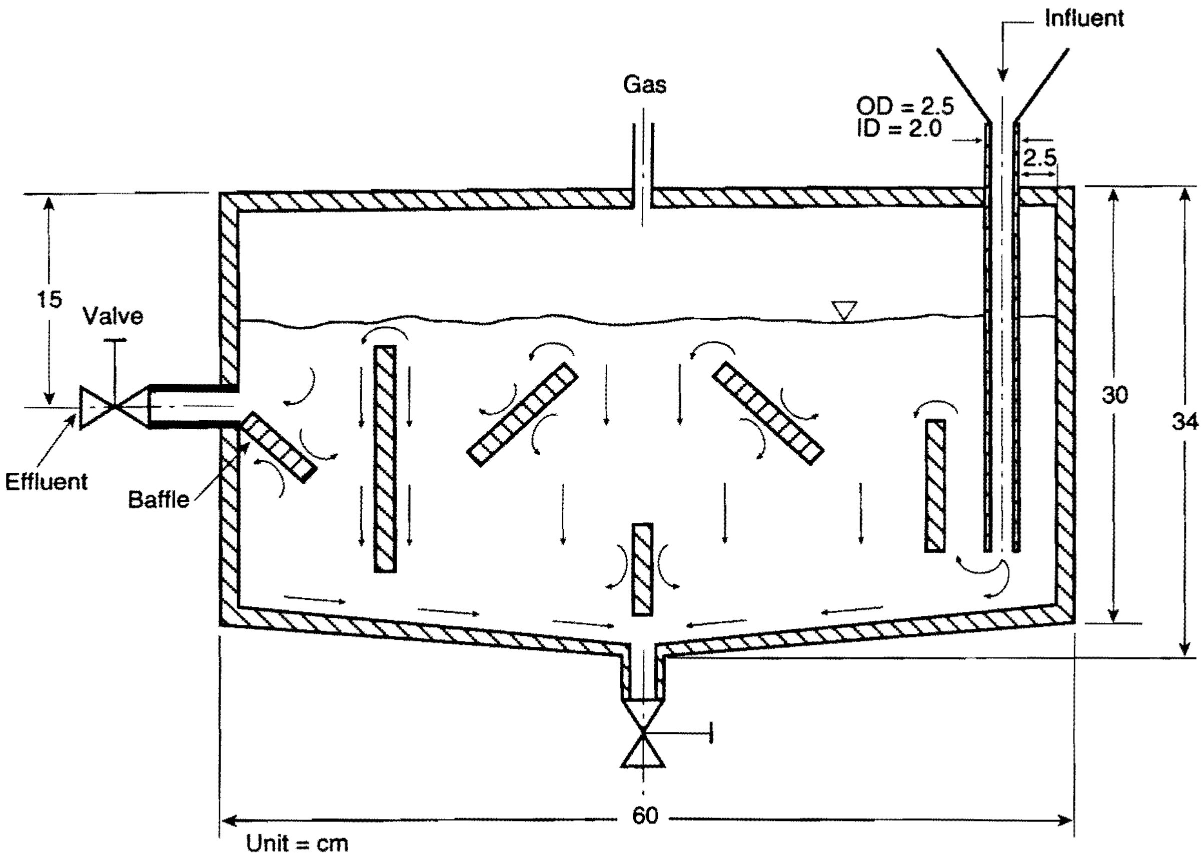

Figure 6. Schematic of anaerobic horizontal-baffled reactor for treatment of swine wastewater (after Yang and Chou 1985)

and a maximum methane production rate of 0.8 l/l/d can be achieved at a TCOD loading rate of 2.5 and 8.5 g/l/d, respectively. Also, it was found that the reactor could tolerate a short, sharp shock loading (100% for 24 hours at an HRT of 5 days) in terms of TCOD removal efficiency. This was shown when the reactor performance remained stable even when a 20% variation in the TCOD loading rate was observed (Yang and Moengangongo 1987). The operational performance of HBAR is comparable with that of the anaerobic filter in treating the supernatant of settled swine wastewater. Because of its simplicity of construction and operation, compared to other anaerobic reactors, this reactor is considered a potential anaerobic treatment alternative for highly diluted swine wastewater containing particulate solids.

Treatment Using Intermittently Aerated Bio-Carousel Reactor

A 2.5-m^3 intermittently aerated bio-carousel reactor (Figure 7) was investigated in the field for the treatment of diluted swine wastewater (Yang and Koba 1988). It is able to increase the SRT and decrease the HRT and provide greater than 90% removal of influent COD and TKN at a COD loading rate of 0.2 g/g MLSS/d or 1.2 g/l/d. Also, it is able to combine the reaction of biological oxidation, nitrification and denitrification, and settling cells in a single unit. The operational and capital costs for a 2000-pig farm, based on a unit cost of $10.50/pig/year, are about the same as that for the HBAR operation. However, some advantages of the IABR operation are its greater ability to remove influent nitrogen, its greater performance stability, and its faster start-up time.

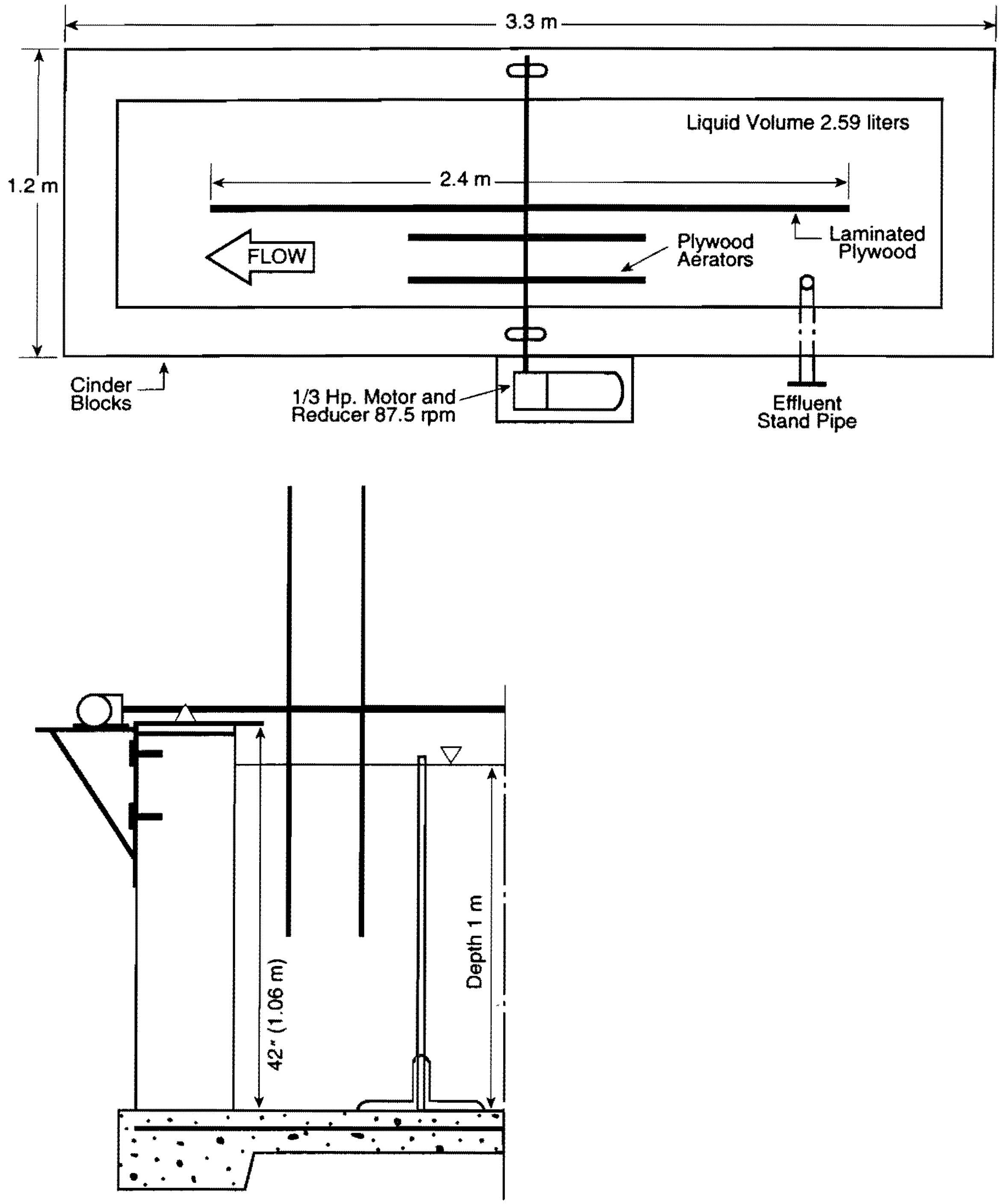

Figure 7. Schematic of intermittently aerated bio-carousel reactor for treatment of diluted swine wastewater (after Yang and Koba 1988)

Treatment Using Combined Bio-Fixed Film and Aquatic Plant

A combined bio-fixed film and aquatic plant system comprised of a series of five 200-liter tanks (Figure 8) was investigated for the treatment of diluted swine wastewater and anaerobically digested effluent (Yang and Chen 1994). This process could remove more than 90% of COD, 95% of TKN, and 99% of TSS at a COD loading rate of 0.1 g/l/d. For a 1000-pig operation, the land requirement is about 0.077 hectare and the unit cost of the system is $2.95/pig/year. CBFFAP is considered a moderately land-saving system compared to the facultative pond and aquatic plant treatment systems.

Summary of Treatment Alternatives

The overall process performance of the various treatment alternatives is summarized in Table 2.

SWINE WASTE BIOTREATMENT PLANT FOR TROPICAL REGIONS

Two types of biotreatment plants for swine waste in tropical regions were investigated. One is the integration of the anaerobic process with sludge recycling and the algal-biomass raceway system (Yang and Nagano 1985a) (Figure 9); and the other is the integration of the anaerobic process with the aerobic treatment system (Yang et al. 1997) (Figure 10). Both treatment systems were installed and operated at the Waialee Livestock Research Farm of the University of Hawaii. Their process performance and application are discussed below.

Integrated Anaerobic Treatment and Algal-Biomass Raceway System

A pilot plant integrating a 20-m^3 anaerobic digester with sludge recycling and a 120-m^3 algal-biomass raceway system was investigated (Yang and Nagano 1984) (Figure 9). A maximum biogas production rate of 1.527 l/l/d (69% methane content) was achieved at a TVS loading rate of 4.23 g/l/d. A sludge TS production rate of 0.82 to 2.62 g/l/d was obtained from a TVS loading rate of 0.76 to 4.23 g/l/d. As for the algal-biomass raceway system, a SCOD loading rate of 0.097 g/l/d achieved SCOD and NH-N removal efficiencies of 94% and 98%, respectively. The operational conditions for the combined 20-m^3 anaerobic process and 120-m^3 algal-biomass raceway system are listed below:

20-m^3 anaerobic process

- SRT: >2.5 days
- Recycled sludge to effluent TVS ratio: 2.0 to 2.4
- Influent TVS concentration: 9 to 13 g/l
- Ambient temperature: 22° to 25°C
- Recycled sludge to influent flow rate ratio: 0.25
- HRT: 1.5 to 9 days

120-m^3 algal-biomass raceway system

- Flow operation: semicontinuous
- Ambient temperature: 22° to 25°C
- SCOD loading rate: 0.04 to 0.15 g/l/d
- TCOD loading rate: 0.1 to 0.3 g/l/d
- TKN loading rate: 0.01 to 0.04 g/l/d
- Applied aeration time: 24, 12, 6, and 3 h/d

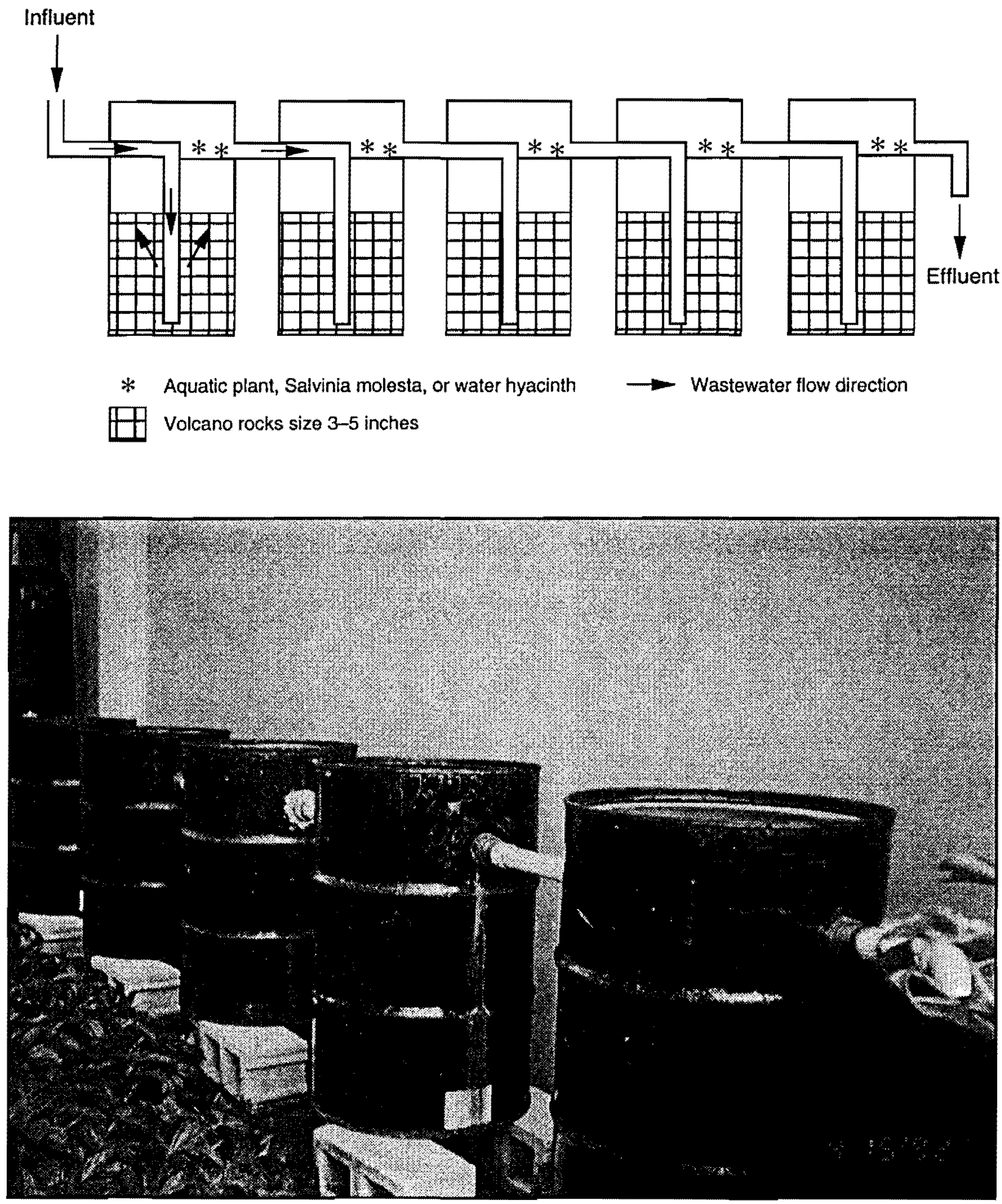

Figure 8. Schematic of combined bio-fixed film and aquatic plant system serial ponds for the treatment of diluted swine wastewater and anaerobically digested effluent (after Yang and Chen 1994)

TABLE 2. Process Performance of Various Treatment Alternative for Dilute Swine Wastewater in Hawaii

Treatment Alternatives	BOD_5 or COD Loading Rate (g/l/d)	Liquid Temperature (°C)	BOD_5 or COD Removal Efficiency (%)	TKN Removal Efficiency (%)
Algal-Biomass Raceway System	0.1 (BOD_5) 0.09 (SCOD)	20 ± 5	97 (BOD_5) 94 (SCOD)	98
Horizontal-Baffled Anaerobic Reactor System	2.3 (TCOD)	30 ± 1	81 (TCOD)	40
Intermittently Aerated Bio-Carousel Reactor System	1.2 (TCOD) 0.7 (SCOD) 0.28 (BOD_5)	26 ± 1	87 (TCOD) 97 (BOD_5)	95
Combined Bio-Fixed Film and Aquatic Plant System	0.042 (BOD_5) 0.1 (TCOD)	19 ± 1	92 (BOD_5) 90 (TCOD)	90

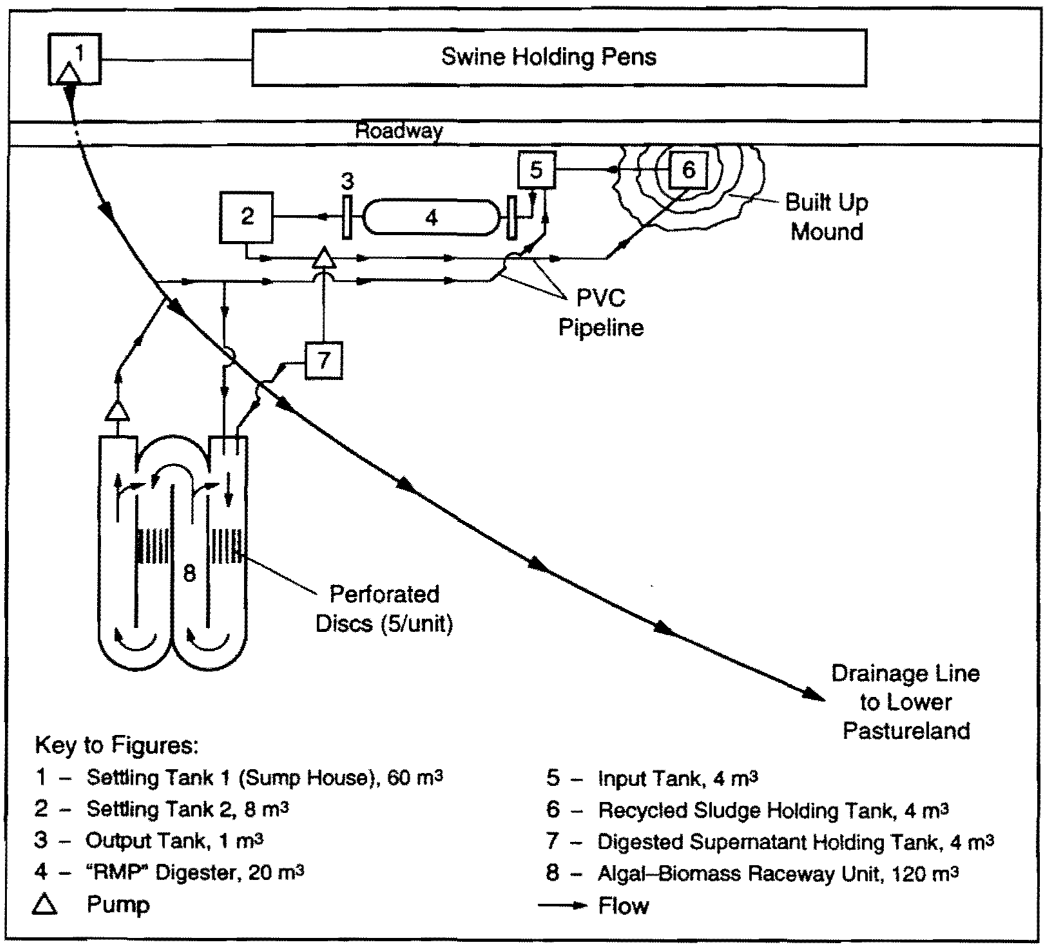

Figure 9. Schematic showing components of swine wastewater pilot plant (after Yang and Nagano 1984)

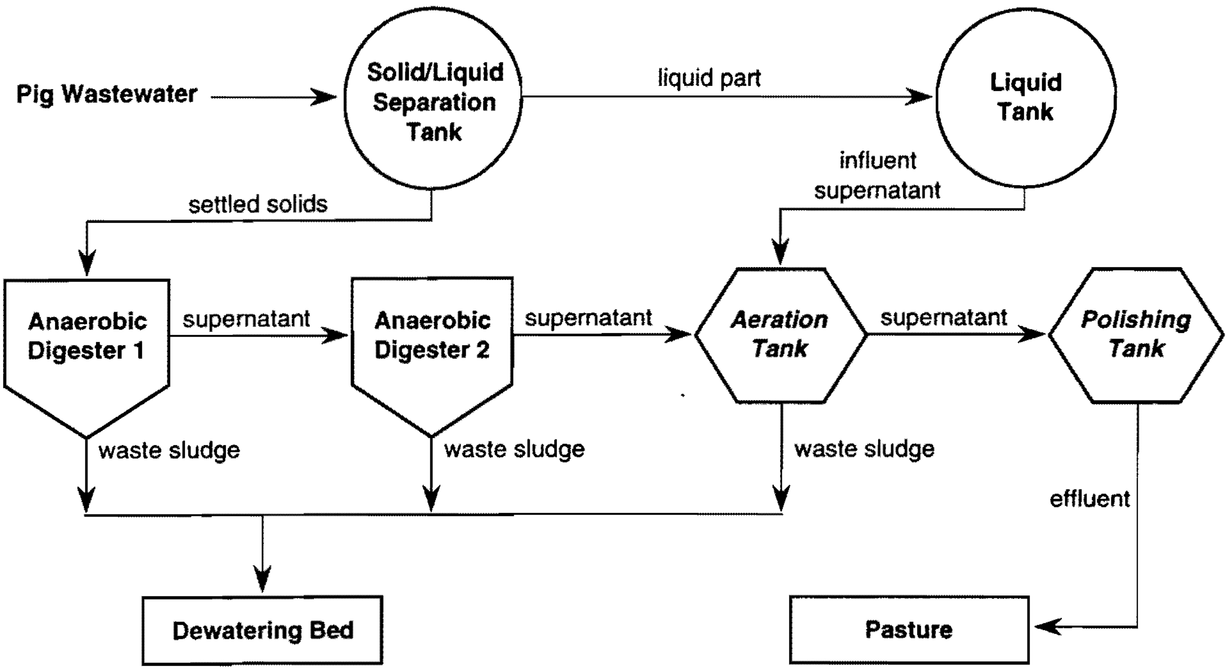

Figure 10. Schematic showing components of swine waste treatment system (Yang et al. 1997)

The settled effluent quality of the combined anaerobic process with sludge recycling and the algal-biomass raceway system is summarized in Table 3.

TABLE 3. Settled Effluent Quality of Combined Anaerobic Process with Sludge Recycling and Algal Biomass Raceway System

Parameter	Average Value
Effluent Settling Time (minutes)	30
HRT for Anaerobic Process (days)	2
HRT for Algal-Biomass Raceway System (days)	18
TCOD (mg/l)	151
$TBOD_5$ (mg/l)	9
SS (mg/l)	135
TKN (mg/l)	397
NH-N (mg/l)	176
NO_3-N (mg/l)	16
pH	7.94

Based on the analysis of energy input and land requirement for the algal-biomass raceway system and mass balance of energy production utilization, integrating the energy production (anaerobic digestion) and energy utilization (dehydration of digested sludge and power requirement for raceway) aspects into one operation provides great potential for successfully operating swine wastewater treatment facilities in tropical regions.

Combined Anaerobic and Aerobic Treatment System

A prototype of a designed 300-pig waste treatment system, including a solid-liquid separation component (12 m^3), two anaerobic reactors (10 m^3 each), one aeration unit (20 m^3), and one sedimentation tank (20 m^3) was investigated (Yang et al. 1997) (Figure 10). It was found that for a combined anaerobic and aerobic treatment system without effluent or sludge recycling on a 240-pig farm with an HRT of 32 days, methane gas production is 0.75 $m^3/m^3/d$ and TS reduction is 72.2% at a loading rate of 3.09 $kg/m^3/d$. The anaerobic reactors at two different stages in the system are able to properly treat the high solid content (10% of TS) of the swine wastes. The aeration unit provides a TCOD and NH-N reduction of 94% and 91%, respectively. The overall settled effluent quality for this combined treatment system is presented in Table 4.

TABLE 4. Settled Effluent Quality of Combined Anaerobic Process (Two Stages without Sludge Recycling) and Aeration System

Parameter	Average Value
Effluent Settling Time (minutes)	4
HRT for Anaerobic Process (days)	32
HRT for Algal-Biomass Raceway System (days)	3
TCOD (mg/l)	411
$TBOD_5$ (mg/l)	58
SS (mg/l)	50
TKN (mg/l)	64
NH-N (mg/l)	39
NO_3-N (mg/l)	20
Total P (mg/l)	33
pH	7.18

The experimental results of this field prototype swine waste treatment system (300-pig design) for land-limited and tropical/subtropical conditions may result in the following benefits:

- Support for livestock producers in animal waste management decision making
- Government action on water quality regulations or administrative codes or guidelines that are applicable to animal wastes
- Exploration of potential joint animal production/processing-municipal cooperation if the energy/fertilizer value is mutually beneficial
- Exploration of potential joint animal production/processing treatment systems

CONCLUSIONS AND RECOMMENDATION

Swine waste treatment systems for land-limited and tropical/subtropical conditions require solid and liquid separation. Present studies demonstrate that the anaerobic treatment process provides the stabilization of concentrated solid for use as fertilizer/soil conditioner and that the aerobic or partially aerated treatment process involving the liquid portion of the swine manure reduces the oxygen demand material for reuse as irrigation water for either land application or crop production. The overall treatment system, including both anaerobic and aerobic treatment of swine manure, provides the benefit of odor control, bioenergy production, fertilizer/soil conditioner production, treated wastewater reuse, and improvement of environmental quality.

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ACRONYMS

BOD_5	5-day biochemical oxygen demand
CBFFAP	combined bio-fixed film and aquatic plant
COD	chemical oxygen demand
HBAR	horizontal-baffled anaerobic reactor
HRT	hydraulic retention time
IABR	intermittently aerated bio-carousel reactor
MLSS	mixed liquor suspended solid
SCOD	soluble chemical oxygen demand
SRT	solid retention time
SS	suspended solids
$TBOD_5$	5-day total biochemical oxygen demand
TCOD	total chemical oxygen demand
TKN	total Kjeldahl nitrogen
TS	total solids
TSS	total suspended solids
TVS	total volatile solids

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PROBLEMS OF INTEGRATED WATER RESOURCES MANAGEMENT ON ISLANDS

Hosei Uehara[1]

INTRODUCTION

In areas of high population growth and of limited resources and environmental capacities, it is not easy to implement such Japanese concepts as "creating an ideal environment for mankind" or "development which helps to achieve consistent human progress." These Japanese ideas for saving humankind were proposed and discussed at the United Nations Conference on Environment and Development in conjunction with official development assistance (for sustainable development) in Rio de Janeiro in June 1992. As a result, Agenda 21 was agreed upon as an action plan for the 21st Century. To demonstrate its commitment to this global plan, the Japanese Government enacted the Basic Environment Law in November 1993 and completed its Basic Environment Plan in December 1994. Local governments followed with the enactment of their own basic environmental plans and regulations.

The Japanese Basic Environment Plan has an international perspective with a long-term goal for realizing a society that is committed to the following themes: "resources cycle," "harmonious coexistence between nature and mankind," "participation of all sectors of society," and "international exchange activities."

In the academic and scientific fronts, the development of a new discipline focusing on comprehensive environmental science (and technology) was promoted. A new field of environmental geotechnology appeared. Environmental technology, unlike conventional soil mechanics and engineering (geotechnical engineering), has more variables for prediction and estimation. According to the Japanese Geotechnical Society (1994), environmental geotechnology takes a more holistic approach to the environment encompassing the atmosphere, hydrosphere, lithosphere, and biosphere.

In Okinawa, the guidelines for formulating prefectural plans had already been established in the 1990 Okinawa Prefecture Comprehensive Land Policy Guidelines. Following a process to control land-use planning, the water resources development plan and related environmental management plans were established as part of the general Okinawa Promotion and Development Plan.

The geotechnical concerns are related to the environmental conditions of islands. Control measures depend on the correct evaluation of the problems and predicted outcomes. The details are too many to cover, thus only the scope of considerations are listed below:

- Ground accidents/disasters and land slides/failures: safety control, disaster prevention, land preservation
- Inland reformations and erosions, loss of soils: soil loses, river and sea pollution, ecosystem protection

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- Reclamation projects in the sea and environmental pollution: soil stabilization and improvement, prevention of liquefaction and disaster, protection of fisheries and coral reefs (ecosystem) from disturbances and pollution
- Land development with and by wastes, recycling and reusing materials: soil improvement and stabilization, protection of ground and groundwater from pollutants, reuse of construction waste materials
- Buried assets, ruins and underground resources: technics for protecting structures, ruins, mining and preservation
- Groundwater pumping: water resources development problems, underground dams, land subsidence and sinks
- Salty and acidic rainfalls: soil and earth pollution, rock weathering, water quality problems with drinking water and groundwater sources
- Seawater rise and its effects: low lands and coastal problems, salty groundwater, application of soil mechanics to engineering problems

WATER RESOURCES OF ISLANDS AND RELATED PROBLEMS

The following are brief accounts of the water resources problems in Okinawa Prefecture, with particular attention to the water demand and supply situation and the development and use of water.

The physical potential for water development from the inland water environment pre-conditions the island water supply and demand situation. Drainage and recycling stemming from the demand side affect safety, disaster-prevention, amenity, and quality concerns.

More details are given in the reference sources listed below. The first three reports are the sources for the development and utility systems. The remaining four reports look into the potential of using rainwater, springs and wells, "resting" water resources, and treated sewage water.

- Report on the Comprehensive Water Resources Development Plan and Investigation on Okinawa Island (1991, in Japanese, H-3)
- Report on the Plan and Investigation of Long-Term Water Demand and Supply (1991, in Japanese)
- Report on the Workshop for Promoting Effective Uses of Water Resources (1992, in Japanese, H-4)
- Investigative Report for Rainwater Utilizing Facilities (1989, H-1)
- Investigative Report on the Present Springs and Wells, etc. (1989, H-1)
- Investigative Report on the Possibilities for the Reuse of Resting Water Resources (1990, H-2)
- Report on the Fundamental Investigation on the Utilization of Treated Sewage Water (1991, H-3)

BALANCING OF WATER DEMAND AND SUPPLY SYSTEMS

A balanced water demand and supply system incorporates measures for the rational use of water. At any given time the available supply of water is determined by the intake and capacity of the distribution system. This available water supply is consumed by a variety of uses and also by nonuses that can serve as a resource for augmenting the supply system through recycling, reclamation, reuse, collection, and so on. A rational usage system would incorporate roof and elevated tanks to control and promote water conservation through instrumentation, user charges, and education.

A balanced water management strategy over time depends on long-term planning that emphasizes both supply and demand factors. For making comprehensive predictions the resource capacities and demand requirements must be fully investigated and discussed. The major demand categories include municipal, industrial, and agricultural water users that are broken down into smaller subcategories depending on their use characteristics. They are supplied from alternative sources (rivers, groundwater, rainwater, brackish water, and seawater), depending upon their particular needs in terms of quantity, quality, timing, and other considerations. Treated wastewater is supplied to municipal and agricultural water users as well as to maintain the flow in rivers. The supply and demand system is integrated through the interflow of water between and among users and supply sources.

Different methods are used to develop alternative water resources. Large high-level dams in the northern area are built by the Japan Ministry of Construction. Okinawa Prefecture is involved in building intermediate-sized dams and waterworks, such as river water intakes, wells, and small desalination plants. The various municipalities maintain smaller storage and intake facilities such as low-level dams and reservoirs, groundwater pumping stations, and spring waterworks. There are also industrial waterworks for developing groundwater, capturing rainwater, recycling, and other activities. Finally, households maintain their own wells and catchment tanks for storing municipal water and rainwater. They also maintain water recycling facilities.

Ultimately, the best strategy for solving problems of water resources management in rapidly urbanizing islands is to aggressively promote water conservation practices in urban planning.

RAINWATER, SPRINGS AND WELLS, AND TREATED WASTEWATER UTILIZATION

Rainwater Utilization

The concept of rainwater use facilities in Okinawa Prefecture is set forth in a Manual for Utilizing Rainwater (H-5) published in 1993 by the Department of Planning and Development. As an example of rainwater use by households, clean rainwater is collected and channeled by drain pipes and screened before it is stored in an underground reservoir, from where it is pumped to an elevated tank and used for nonpotable purposes (e.g., flushing toilets, washing cars, and landscape irrigation).

The fundamental considerations for using rainwater include structures, water quality, and maintenance factors as follows:

- Structures: rainwater utilities may be installed in public buildings, commercial buildings, and private residences.
- Water quality: the rainwater must be safe for use, cause no public nuisance, and cause no harm to the building facilities.
- Maintenance: rainwater utilities must be carefully planned and carried out.

Springs and Wells for Water Resources

The concept of spring water use is described in an Investigative Report on the Possibilities for the Reuse of Resting Water Resources (1990, H-2), published by the Prefectural Department of Planning and Development. It applies to certain areas such as Naha, Urasoe, Ginowan, and Okinawa City.

The uses of waters from springs and fountains depend on the scale of the resource as follows:

- Large-scale water resources are used for regional water supply and for dry seasons.
- Small-scale water resources are used for supplementary water and for landscape sprinkling in parks.

The use of well water depends upon the depth of wells as follows:

- Shallow wells are used as cooperative water resources for parks and community purposes and as private water resources for households.
- Deep wells are used primarily as water sources by corporations.

Sewage and Reuse of Treated Water

Actions of Okinawa Prefecture

The actions at the prefectural level are covered in a Report on the Fundamental Investigation on the Utilization of Treated Sewerage Water (1991, H-3). An outline of Okinawa Prefecture Municipal Basin Area Sewerage Works shows how treated wastewater is classified according to major use categories that are functionally broken down into specific use types. The classification scheme takes into consideration the natural flow properties of the water source and their utility to the intended purposes of reuse.

Municipal wastewater treatment is organized according to sewer service areas as follows. In the middle basin area, ten municipalities are serviced by two filtration and disposal centers located in Naha and Ginowan. In the Nakagusuku Bay basin area, five municipalities are serviced by the Gushikawa filtration and disposal center. In the Nakagusuku Bay southern basin area, four municipalities are serviced by the Nishihara filtration and disposal center.

Maintaining a healthy flow of water in rivers and streams is an essential part of harmonizing humankind's use and reuse of water in the water cycle while securing the natural amenity values of water for sightseeing and other recreational activities

Toward this end, a number of pilot improvement plans have been developed, including Kumoji stream flow and clean up in Naha City, Nishizaki aquapark in Itoman City, and Nago central park and aquawalk along Kohchi River in Nago City.

In 1995, a basic plan for environmental conservation was released for Naha City, followed by the release of a WELL (Water, Environment, Linkage, Life) plan (H-7). Under these plans, retreated water can be used (supplied) in three ways: individual building circulation, small-area buildings circulation, and wide-area circulation supplied by a filtering center.

To recap, there are various purposes for using treated wastewater, including (1) supplementing the water supply, (2) providing a secondary water resource, (3) lowering system costs of water supply and sewage facilities, (4) restoring the environment, and (5) enhancing waterfront property and shoreline areas for a better quality of life. For all these purposes, water quality must be considered for safety reasons and for the specific use requirements that differ for the many end uses of water. There are many safety and quality requirements for industrial water, agricultural water, firefighting water, environmental conservation, and reservation for groundwater recharge, and so on, that vary not only by the type of use but also by the place and timing of use. Recycling water for reuse can be problematic, and Okinawa has been gearing up to meet the challenge.

CLOSING REMARKS

Overcoming water resource problems on islands is crucially important for the survival of human communities and their ecosystems. The popular concept of "sustainable development" on a global scale is even more important for small islands where the limiting factors are compressed over space and time. The Japanese equivalent for symbiosis is *kyosei* and for recycling/reuse is *junkan*. These concepts must be taken into careful account in the development and use of island water resources. They are essential for keeping a balanced flow of water through the atmosphere, biosphere, hydrosphere, and geosphere of islands. The development and use of water not only determine the balance of demand and supply for a planning period, but also affect the potentially permanent flow of water in terms of both quantity and quality. While this may seem to be a concern for the more distant future, it is also current due to the actions of the past. Emphasis must be given to an integrated approach of water resources planning and management. Such an approach can secure the natural water resource base for the sustainable development of islands through conservation practices that harmonize the socioeconomic values with the natural biophysical interrelationships of island water environments.

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島嶼国における水資源問題
沖縄諸島における水のリサイクルと再利用に関する事例研究

琉球大学工学部　上原方成

１．はじめに

土地資源と同様，地球の諸々の資源およびエネルギーには制約があり，それぞれについて環境容量には限界がある．人口が増大しつつある地域では，それゆえ，「人類の理想的な環境の創造」とか，「永続的な人類の発展をもたらす開発」といった考え方を実際に実現することは容易ではない．人類の救いに関する考え方を提案するために，持続可能な開発に関する国連環境開発会議が１９９２年にリオデジャネイロで開催された．そこでアジェンダ２１が議論され，来たる２１世紀の行動計画として策定された．

日本国政府はこの動きを受けて，１９９３年１１月に環境基本法を施行し，１９９４年１２月には環境基本計画を決定した．続いて自治体において環境基本条例や環境基本計画が決定された．国の環境基本計画は国際的な視点も含んでおり，また，「資源循環」や「人間と自然の共生」，「社会のすべての主体の参加」，「国際交流行動」といったテーマに沿った社会が実現できるような長期的な目標を有するものである．

沖縄県においても，とくに島嶼の自然環境に留意した環境管理や計画が求められる．水，土，生態とこれらの関係がひときわ微妙で，開発においては細心の注意が必要となる．そこでまず，本稿では，水を考えるうえで，基礎となる，地盤環境について紹介し，その後，水循環にかかわるさまざまな課題や提案を紹介する．

２．環境地盤工学について

近年，急速に，アカデミックで総合的な環境科学や工学が発展してきている．そのなかで，環境地盤工学は環境工学の発展とともに形成されてきた．　環境地盤工学は，既存の土質工学や地盤工学とちがって，予見的，あるいは評価の側面をより多く持つ．そして，環境に関してホリスティックなアプローチをとるものである．すなわち，大気圏，水圏，地圏そして，生物圏にわたる，広範な視野を持つ．それゆえ，水環境を考える際にも，環境地盤工学からの視点が重要となる．

以上のような状況のもとで，沖縄県では総合土地対策要綱（１９９２年）をもとに，土地利用基本計画が定められ，また沖縄県環境管理計画が１９９４年に決定された．

ここで，地盤および地質（ground/earth）すなわち，地盤環境(environmental geo-technics）に関する諸問題の状況を以下にまとめておく．

1）地盤事故／災害(Ground accidents/disasters)と地すべりと事故(land slides /failures)

安全管理，災害防止，土地の保全

2）土地改良(land reformations) と浸食(erosion)と土壌流出 (soil flowout)

土壌の消失と，河川や海域の汚染，生態系の保護

3）沿岸の埋め立てと環境汚染

土質の安定化と改良，液状化 (liquifaction) の防止と災害，漁業や沿岸部やリーフの生態系の撹乱や汚染の防止

4）廃棄物やリサイクル／再利用されたものを利用しての土地開発

土質安定と改良，土地や地下水汚染の防止，建設廃材の再利用

5）埋蔵文化財／遺跡 (burried assets/ruins) と地下資源

構造物や遺跡の保全技術，採掘および保全技術

6）地下水のくみ上げ

水資源開発問題，地下ダム，地盤沈下／沈降，海水侵入

7）飛塩害や酸性雨

土壌／土質汚染，岩盤の風化，飲料水／地下水の問題

8）海水位上昇による影響

低地や沿岸の問題，地下水の塩水化，土質力学／工学的諸問題

水循環は大気圏よりもたらされる降水から始まるといえるが，大地に受け止められた後は，地圏や生物圏と密接な関係をもちながら，海洋や大気圏にもどる．大地の上で展開されるわれわれの日常の生活や経済の活動と密接にかかわるだけに，今後の環境地盤工学の発展と，とくにその島嶼環境への積極的な応用が期待される．

3．島の水資源と関連する問題

以下に沖縄の島々でみられる水資源の問題，とりわけ，水需給と開発利用にともなう問題の現状を簡単に述べておきたい．

3－1．島嶼における水資源開発，沖縄県の場合

沖縄県においては，戦後から本土復帰以後，ながく，ダムの建設による水資源の開発が進められてきた．それは，沖縄が，島嶼という自然環境のもとで，河川長が短く，集水域が小さく，河川流況の変化が激しいといった特徴を抱えるうえで，歴史的にもながく続いてきた水不足と断水による不便を克服することが県の発展にとって最重要課題であったた

めである．

しかし，９０年代に入り，あらかたの河川やダムの開発計画が実施され，供給が需要に追い付いてきたことや，近年特に，地球環境の視点から，稀少な生物の重視と生態系の保護が大きく取り上げられ，ダム開発のみによる水資源確保は物理的にも，社会的にも，多くの問題を含むと考えられるようになってきた．そのような，社会的な変化をうけて，「沖縄本島総合水資源開発計画調査報告書（沖縄総合事務局，１９９１）」や「沖縄県長期水需給計画調査報告書（沖縄県，１９９２）」「水資源有効利用推進検討会報告書（沖縄県，１９９２）」では，従来のような，河川開発による水資源確保の他に，分散的で，多様な水資源の確保，さらに積極的に良好な環境の創造を目指して，生活環境におけるアメニティとしての水環境整備の重要性を指摘している．

沖縄県では，他の本土の府県とは異なる水環境の歴史と現状をもっている．それは，県土のかなりの地域が琉球石灰岩で覆われており，それが良好な地下水を湧水や井戸といったかたちで，歴史的に人々の生活を満たしてきたこと，また，あわせて，雨水が良好な飲料水源として，生活のなかで取り込まれていたことから，地下水や雨水利用が，本土とは違って，現実味をもって実現可能な供給源として検討の対象とされるようになってきた．

さまざまな水資源を循環させ，利用することの可能性が他の地域に比して大きな意義を持つ．そのような点から，歴史的な雨水利用を振り返り，現代的な利用方法を検討するための「雨水利用施設調査報告書（沖縄県，１９８９～９０）」や，古くから使われてきた湧水や井戸水の現況を把握するための「湧水・井戸等実態調査報告書（沖縄県，１９８９）」，さらにそれらのうちで，利用されなくなった水資源を再び利用するため，「遊休水資源活用可能性調査報告書（沖縄県，１９９０）」が出された．また，都市独自の大きな水源ともいえる下水の循環を検討するために「下水処理水利用基本調査報告書（沖縄県，１９９１）」など（いずれも日本語）がすでに発行されている．

３－２水需要供給システムのバランス

将来の総合的な水資源を予測するためには，水需給の均衡を維持する水資源開発やあらゆる種類の水資源の能力を検討する必要がある．水需給（水量に関して）は以下に示すように検討されてきた．

１）水需要予測

都市用水　　；生活用水／家庭用水，店舗／事業所等用水
工業用水など；産業用等用水，観光用水，基地用水
農業用水ほか

2）水資源開発

国営ダム

沖縄県企業局（ダム，河川取水，井戸，海水淡水化施設など）

市町村独自水源（ダム，貯水池，地下水，湧水など）

工業施設水源（地下水，雨水，水の循環利用）

家庭用水源（雨井，井戸，水の循環利用）

まとめると島の水資源問題の解決を果たすためには，前項でみたような，さまざまな分散的で多様な水源の利用を検討するとともに，単にポイントソースとしてのそれらの水源の検討にとどまらず，さらに積極的に，節水型の都市計画および土地利用計画など，都市を形作る基本的な計画の中で，広範な視野から水循環をあつかい，水循環と調和した都市づくり，また水循環と共生する都市での生活や経済のありかたが，よりいっそう検討されなければならない．

4．雨水および処理水の利用に関する沖縄の事例

4－1．雨水の有効利用

沖縄では，雨水利用を構想の段階にとどめるのではなく，実際に普及をはかるために行政の努力が行われてきた．

沖縄県企画開発部（Dept. of Planning and Development)では１９９３年に家庭や事業所での雨水利用を促進するために，「雨水利用マニュアル」を発行した．雨水利用に関する基本的な考え方は次のようにまとめることができる．

1）利用対象(utilizing objects）；

公共施設，住宅，商業ビル

2）水質；

安全で公害をもたらさないこと，また建築物／施設にとって害がないこと

3）維持管理；

慎重に検討され，また継続推進されること．

このマニュアルの中で，家庭や事業所など，さまざまな施設における雨水利用の実例が報告され，より具体的に県民の利用を促すような方策がわかりやすく示されている．

４－２．水資源としての湧水，地下水

沖縄にはかつては利用されていた湧水，泉，井戸水，地下水が遊休化しているものが多数ある．利用施設の老朽化や，生活様式の変化，都市化にともなう水質の悪化など，利用が困難になるとともに，加えて水道水利用の利便さから，多数が放棄されるに至っている．そこで，沖縄県企画開発部では遊休水資源の見直しを計るため，１９９０年に遊休水資源に関する報告書を発行した．その中で，那覇，浦添，宜野湾，沖縄市の地域を対象として検討しており，その利用の考え方を示している．

湧水，泉：大規模水源；乾期の水資源としての地域への水供給，
　　　　：小規模水源；補完的利用水や，公園などへの散水用余剰水として
井戸水　：浅井戸；共同水源　公園などに利用
　　　　　　　　　個人水源　家庭用
　　　　　深井戸；共同水源，商工業用水源などとして

遊休水資源の復活には克服すべき課題も多くあろうが，身近な資源であるだけに，今後の活用が望まれる．

４－３　下水および処理水の再利用

１９９１年に発行された下水処理水の有効利用に関する報告書の中で，利用方法，経済的な課題，維持管理，企業化に関する問題などが検討された．沖縄県の公共下水道，流域下水道はそれぞれ，複数の自治体からの下水を集め，以下のように，各下水処理場で処理される．

１）中央流域下水道（１０自治体）　；那覇下水処理場，宜野湾下水処理場
２）中城湾流域下水道（５自治体）　；具志川下水処理場
３）南中城湾流域下水道（４自治体）；西原下水処理場

各下水処理場で処理された水の利用については主として環境用水として位置付けられよう．すなわち，河川上流に放流することで，河川の水量を維持し，水質の改善，生物の生息の場を確保するための河川維持用水や，また，水にかかわる景観（観光），レクリエーションの場を提供するための用途がイメージされる．

実際のパイロットプランとして，那覇市の久茂地川の流量維持と水質改善への利用や，名護市の名護中央公園と幸地川での下水処理水の環境用水としての利用が検討された．

1）名護市の事例

名護市さくら公園，中央公園では，本来なら行政管轄区分の問題から，実施が困難であった下水道事業と公園事業の一体化を実現させ，下水処理水を再生処理施設で高度処理したのち，せせらぎ水路に放流，循環させ，最後は自然の河川の維持用水として放流する計画で，良好な親水空間を生み出すものである．すでに建設も行われている．

2）那覇市の事例

１９９５年に環境保全基本計画が示され，また「WELL PLAN －水(Water)，環境(Environment)，連鎖(Linkage)，命(Life)」が同年，報告された．下水処理水が次の三つの方法で利用される．すなわち，処理場からの水が，個々のビル単位での循環，小区域でのビル間での循環，広域の循環に供給される．再生水を用いた清流の復活では，自然素材の使用，緑との一体化，歴史的・文化的遺産との一体化，生物の生息場所の確保など，生態系に配慮した水辺の創造が検討されている．

以上の事例のほかにも，他の地域，たとえば糸満市アクアパークなどでも施行されている．

４－４．水循環にともなう課題

湧水や井戸水，雨水の利用，下水処理水の利用など，多様な水資源の利用の目的は，１）補完的な水供給システムとして，２）２次的な水資源として，３）水供給および下水処理施設についての経費節減，４）水環境の回復，５）生活にアメニティーをもたらす，などである．それ故に，水質は安全なものでなければならず，また，水道水源，農業用水，環境保全用水，防火用水，地下水灌養水など，水の循環利用は，それ相応の諸問題を克服せねばならない．

また，処理水を用いた親水空間の創造にみるように，水循環の創造は工学的な解決だけでなく，多数の行政主体の管轄を横断的に縫合せるような取組が必要であり，行政的，制度的諸課題を克服する必要がある．すでに県内で実施されつつある建設事例は縦割の障壁を超えるものであり，これらの取組は高く評価されるとともに，行政の質的な変革にむけてのさらなる努力が望まれる．

５．結論

島嶼国においては，水資源問題は島々の生活において重要であり，また，島の生態系にとっても重要である．それゆえ，非常にポピュラーとなった概念である「持続的発展」の

思想は，とりわけ小さな島々においては慎重に実践されなければならない．そのことはとりもなおさず「共生」と「循環」が地球的な視点から検討されるのと同等に，島嶼においても重要であることを意味する．

島の環境においては，気圏，水圏，生物圏，地圏を通じての水の流れは，水資源の開発と保全を行う際に絶えず配慮されなければならない．また，社会経済システムの中で，水を開発し，利用することは，人々の生活における水需要のバランスを決めるだけでなく，水質や水量に多大な影響を与え，かつ島の将来の水の流れにも影響するものである．

島の水環境における事業や保全行為と自然の相関関係とを調和させ，また水の需給バランスをうまく保ことによって，水資源問題の総合的な解決，進展が期待できよう．そして，それによって，島嶼国での持続可能な経済発展と水保全システムは成功裏に進展するであろう．

最後になるが，筆者はこの場をかりて，ここで引用した沖縄の水問題にかかわる多くの調査報告書の著者ならびに関係機関に心より感謝するものである．また，本文をまとめるにあたって，大阪学院大学三輪信哉博士のお手をわずらわせたことを記して謝意を表する次第である．

＜注記＞今回は紙面の都合により，図表，写真などをすべて省略したが，後日，稿を改める際に完成報文としたい．

WATER RESOURCES MANAGEMENT PLANNING FOR OKINAWA

Nobuya Miwa[1] and Hiroshi Yamauchi[2]

Abstract

The geographical limits of island water resources largely define the scope of island water resources management. Conventional water development planning often views water resources as unlimited for development. While it is possible to apply such an approach to islands where the amount of water used is still well below the available natural sources, geographical limits are nevertheless always present. It is therefore prudent to take such limits into account as preconditions in drawing up management plans.

In the case of Okinawa Island, water resources development is encroaching into the limited habitats of rare native species of plants and animals, and any further encroachment is sure to be controversial. The problem, it appears, is not so much the development of scarce water resources to offset the insufficient supply but the changing patterns of resource use and water consumption that reflect increasing demands. The more crucial issues are likely to be on the demand side rather than on the supply side.

At the global level, environmental problems have encouraged a re-thinking of the current patterns of mass production and consumption. New ideas now being implemented include backward planning (in contrast to forward planning), zero emissions planning, and cleaner production techniques as part of end-of-pipe technologies for the future. It is important that these new approaches be considered in dealing with the issues of limited water resources in islands.

In the context of Okinawa, planning for water resources management should consider the following four basic strategies:

1. Backward planning. Current long-term water resources planning in Okinawa assumes an increasing trend in water demand for the future and the need to develop new water resources to meet the projected demand. Backward planning would establish an upper limit on the traditionally available water resources and focus planning on changing demand patterns within that limit.

2. Cyclic planning. Cyclic Planning involves changing demand patterns, saving water, recirculating and reusing it, and substituting or utilizing local water resources instead of relying on imported water. It is essential that institutional rules and administration change significantly.

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3. Comprehensive river basin management. Rivers were often managed as a source of water and a channel for draining storm waters. A more comprehensive river basin management approach would consider the channels and their watersheds as an integrated whole and be oriented toward water conservation. Such an integrated approach would promote active use of underutilized local water resources, restore both river water and groundwater, and enhance the value of rivers for scenic and ecological purposes.

4. Citizen participation. Water resources planning that actively involves changing the patterns of water use recognizes the importance of demand factors that drive consumption trends. Successful planning of this sort requires that consumers understand and support the management plans; this means that their involvement in the planning process is necessary. Effective planning for management of river basins is not possible without the active participation of those who live and work there. For this reason, citizen involvement is increasingly important.

The limited nature of island water resources requires that the basis for water resources planning change. The traditional planning paradigm that focused on expanding the supply needs to be balanced with a demand management approach. In order to become more water conserving, specific plans must take into consideration the above four strategies.

沖縄の水資源管理の計画に関する一考察

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1．はじめに

これまで，著者らは，沖縄本島やオアフ島などの水収支ならびに水資源問題について検討を加えてきた．島という空間的にも水資源の面でも制約のある環境下での水資源の管理について検討を加えるものであり，できる限りデータにもとづいて地域調査と実態分析に基づいて研究を行ってきた（文１～３）．本稿では，有限な資源環境下における水資源の管理のありかたを対象に，特に沖縄本島の状況を念頭におきながら，今後の水資源の管理ならびに計画について考察すべき点について検討を加えるものである．

特に次の三点について検討を加える．すなわち，１）資源・環境制約下での活動に関する近年されるようになってきた諸概念の検討，２）水資源開発がほぼ計画どおり展開してきた現状下で検討すべき，沖縄本島で生じている水に関する問題の検討，３）今後の水資源制約下での長期の管理と計画に関する方向性の検討，である．

2．これまでの水資源計画のありかた

島の水資源の開発は，空間的にもまた自然の水循環の点でみても，技術の進展によって絶えず制約を克服する過程であった．戦前から戦争直後，当初の家庭単位での雨水の利用や井戸を利用する段階から，簡単な水道技術によってせいぜい数百mから数kmの範囲内で水を引く簡易水道の段階，そしてそれらを連結した程度の数町村にまたがる水道の段階へと移ってきた．また戦後はアメリカの統治下で，各基地を結んでの統合水道の建設，そして米軍による全島統合水道計画がたてられ，本土復帰により本島で開発可能な全ての河川でのダム計画調査を基に，中南部の水利用を供するための北部のダム開発が勧められた．

需要量に比して供給量が同程度かそれ以下の状況では，渇水が生じる恐れがあり，ながらく，ほとんど毎年にように長期にわたる渇水にみまわれるという状況にあった．このような状態を克服するために，検討され，建設されたのが，恒常的に水を供給できる海水淡水化施設である．海水淡水化施設は常時の利用によってダムからの取水量を減らすことができ，結果として，ダムの貯水量を渇水に備えて温存することができるという，大切な機能を持つ．

今後とも水の需要が増大するとの長期予測がなされており，現在もダム建設が進行中である．他方，さらなるダム開発については，北部の稀少生物の保護にたいする関心が高ま

るにつれ，新規の開発は厳しいものとなりつつある．また，量的に安定した供給を可能にさせる海水淡水化技術はモジュールの交換や多量のエネルギー消費を伴うため，地球環境の視点，ならびに経営的な視点からみれば，安易に推奨できるものではない．多額の費用とエネルギーをかけて浄化された水が，水洗便所等の低質の用途に供されることの問題もある．

これまでの水資源開発の計画手法は，人口と一人当たりの水消費量の原単位の今後の趨勢を予測し，それらの積を延長して水資源の需要量を予測し，その上で，必要となる水資源を開発するというものであった．このような方法を取る限り，水を利用する住民の，水に対する節水意識を形成したり，あるいは多様な循環を需要サイドである都市に組み込もうという意識は生じない．また，需要の増大を前提とした上で水資源を開発することは，遠隔の地に水資源を求めることとなり，自然の破壊やその地の住民の生活の変容，将来の開発の可能性の奪い取りなどの影響を残す．

今後の水資源の長期的な計画をたてる場合に重要なのは，島の水資源を有限として捉え，その上限の設定をもとに，今後の計画をたてるという視点であろう．すなわち，水資源有限の立場にたっての計画である．

３．地球環境を有限とする立場から生まれた幾つかの概念

近年，環境問題や開発に関する国や自治体の対応はようやく変更の兆しが見えてきた．ダム建設計画についても，計画の見直しや，ミティゲーションや親水性を配慮した建設を行うなど，である．これまでの国の開発一辺倒の考え方とは異なり，５年，１０年と時間の経過にともなう需要の変化に応じて，計画を見直そうとする姿勢である．

ここで少し水資源の検討とは離れるが，地球環境問題に対処するために生み出されてきたいくつかの概念について検討を加えておきたい．それらは地球環境を有限とする見方にたって，現在の諸活動を見直すために提案された基本的な概念である．それらを検討することは，水資源を有限とする立場にたっての水需給計画に対して重要な視点を提供する．

１）環境容量の割戻しについて

地域の資源，あるいは地球の資源は有限であるにもかかわらず，これまではあたかもそれは無限であるかのように捉えられてきた．水が経済学では自由財として捉えられてきたことからもそのことがわかる．資源の量に対して，人間の経済活動が相対的にまだ小さかったとこや，あるいは資源総量，人間の活動総量の計測，そして両者の関係に関する科学的認識が遅れていたことにその理由を求めることができよう．しかし，今や地球環境，資源の有限性は誰の目にも明らかであり，議論の余地はない．

このような資源や環境が有限であるという見方から，地球温暖化の解決に向け，温暖化

をくい止めるためには，算出された温暖化原因物質の総量から逆に，温暖化を引き起こさない程度の温暖化物質の排出可能量を算出し，次のステップとして各国からの排出量に割り戻す，という方法がとられている．当然，各国間で，また国内の各産業間での排出可能量をどのように分担するかは極めて難しい課題であり，目標値の設定と，実施の具体的方法が最重要課題として検討されている．

これまでにも日本国内で，都市の大気汚染や閉鎖性水域を対象とした総量規制が行われ，環境保全において重要な成果をおさめてきた．しかし地球規模の環境の容量を算出し，そこから活動の総量を逆算する方法についての世界的な合意に向け真剣な討議がなされているということは画期的なことである．

このような環境容量の割戻しの考え方は，１９７０年代に水環境についての検討から環境容量概念を提示した末石冨太郎（文４）や，１９８０年代に同様の視点からエネルギーソフトパスを検討したエイモリー・ロビンズ（文５）に，先駆的な成果を見ることができる．

すでにオランダのＮＧＯでは地球環境容量から逆算したオランダ人一人あたりの環境容量を算出している（文６）．また資源・環境制約下での計画論として，これまでの将来予測とそれに基づく資源開発計画の手法をforward な計画とし，これに対して，将来の環境・資源制約から逆に現在の活動を規定する方法をbackwardな計画としている（文７）．

水の利用においても水資源の有限性や排水域の環境容量の制約から，さらに我々の活動に割戻し，あるいは制約を意識して，各活動主体が自らの活動を変更するような概念・枠組みが必要とされている．

２）ゼロエミッションについて

このような概念の一つとして提唱されているのが，『ゼロエミッション』である．ゼロエミッションは，一企業での排出を減少させることを目的とするだけでなく，ある企業の廃棄物が，他の企業にとっては資源となるよう，企業間の資源と廃棄物の関係を見出すことによって，循環を形成し，全体として資源消費量，廃棄物総量を削減しようとするものである．日本国内でも，鹿児島県の屋久島を対象としたゼロエミッション計画の事例研究や，ゼロエミッションを計画理念においた工業団地の建設が行われている．また，企業の廃棄物の質・量をデータバンク化し，それを資源として求める企業に情報を提供するシステムを形勢することもゼロエミッションの考えかたの具体例である（文８）．

廃棄物と水，エネルギーの流れについてはＬＣＡの説明で引用される図のように，両者には流れかたに大きな違いがある．廃棄物は資源採取から始まって，輸送，加工，販売，廃棄と，生産者から消費者へと渡されてゆくが，水およびエネルギーはその流れとは言わば『直角に交わる』方向で，各主体で取り入れられ，廃棄される．したがって，エネルギーや水の場合には，他の資源のようにある企業の廃棄物が他の企業の資源になるという

のとは異なるといえよう．ある産業の排水が他の産業の水源になるということは，水が流路によって空間的に規定されているので，他の資源ほど容易ではない．しかし，排水を雑用水として供給する方法や，温排水を養殖や冷暖房の熱源にするなどの技術的な工夫も多々実用化されており，ゼロエミッションの考え方に近いものと言えよう．

3）ＥＯＰとＣＰについて

これらは企業に於ける環境負荷となる排出物の処理の技術に関する考え方である．

通常，製造業者は，生産活動を行う場合に，生産工程から生じた廃水を，政府が決める環境基準を満たすように，工場敷地内に処理施設を設けて処理し，排水している．大気汚染物質や廃棄物についても同様である．このように生産工程からでた廃水を最後に処理するため，管の末端で処理するとの意から，このような技術をＥＯＰ技術（End of Pipe Technology）という．

対して，たとえば洗浄工程で大量の水を使っていたものを少量ですむように技術改善したり，あるいは水を使わない工程に切り換えるなど，廃水そのものの水質改善や，量を減らすなどの工夫を生産工程の上で行うことによって，工場敷地内からでる排水を改善するような工夫をＣＰ技術（Cleaner Production Technology ）と言う．このようなタイプの技術には，生産工程の組み換えや従業員の教育など，ソフトな技術も含まれる．例えば，醸造業で，工程を変更するなどして，排水の質および量共に改善でき，改善の為の追加投資に比して，節減により経営上はプラスの効果をもたらした例もある．

このようなＥＯＰ技術からＣＰ技術への変更を目指すことは地球環境問題の解決のひとつの方向性として，さらに多くの企業に適用されてゆくべきものである．

以上のふたつの概念は，主として生産活動で，資源取り入れ，加工，廃棄の，資源のフローの過程で，End of Pipe と示されるように，廃棄側すなわちoutputに着目した考え方である．しかし，生産工程に取り入れられる資源やエネルギー，水など，資源側すなわちinput の側にも拡張され得る概念であろう．

また，水資源を対象とした場合，これらの考え方は水利用を行う主体ごとに適用できる考え方である．家庭における節水努力や節水機器の活用など，ＣＰの概念を適用して，水消費，汚水排水からみて，いわばプロセスの変更，工夫により，消費量あるいは環境への付加を減少させる方法である．

４．沖縄の水資源の管理について検討されるべき課題

筆者らは沖縄の水資源問題として，南北間での消費地と供給地の間での資源配分の不均衡，それによって生じるコンフリクト，その元となる水資源開発計画や制度的枠組みについて，これまで検討を加えてきた．ここでは，今後の水資源の方向性を検討するためにい

くつかの事例をあげておきたい.

1）南部の一部事務組合による水資源管理

近年まで南部の地域では地下水を水源として，一部事務組合により独自の水道供給が行われていた．しかし，水量の限界から安定供給が困難であったこと，石灰岩層中の地下水を水源とするために地表からの汚染が懸念されたこと，一部事務組合によって経営されてきた既存の管路網を利用することで追加的な建設費を節約できること，などの理由から県企業局の水道に統合され，地元の水源は利用されなくなった．放棄された貴重な消費地の地場の水源の活用について見直すことも重要である．

2）簡易水道の県企業局の水道への統合

戦後，全島統合水道が検討される前，各集落が古くから用いてきた湧水などを水源として，集落ごとに簡易水道が建設されてきた．現在でも離島においては多数，当時の簡易水道が改良を施され引き継がれて使用されている地域もみることができる．本島においては，簡易水道は，南部の一部事務組合の水道と同様の理由で，また，集落の共同作業によって行われていた簡易水道の維持管理が，生活が都市化するとともに困難となることも一因として，広域の水道に統合されてきている．経営的には地場の水源を放棄し，統合的な水道に依存することは効率的ではあるが，一元的な水道に依存することによる様々な問題をもたらす．

3）親水空間の創出について

河川を対象として，親水空間の創出が近年全国的な取り組みとしてされるようになってきた．そこで指摘される点は，生物がそのライフサイクルのすべての段階で生息しやすいような工夫がなされているかどうか，周辺の雑木林が河川に落とす影が生物の良好な生息環境を提供しても，計画対象とされずに他の土地利用に転用されたり，また，河川が雨水排除目的の延長線上で親水機能を付与されるために流量が確保できなかったり，と，豊かな水と生物の環境が心豊かな空間を生み出すといった視点に欠けることもある．地域に密接に関係した空間として地域の人々の利用と愛護が重要な位置を占めるとの視点に立てば，計画段階での近隣住民の意見が反映されることが必要であろう．

4）広域下水道問題

本島の中南部地域に広域下水道計画が立案されている．その際に計画に対して反対をとなえる団体から問題点として，将来の過度の需要を前提に大規模な下水道建設が予定されていること，その計画の段階で住民の意見が反映されなかったこと，が指摘されている．

以上の問題は地場の未利用の水資源の利用という視点から，地域あるいは流域を空間単位として検討されるべき問題であるといえよう．

５．水資源の流域管理の必要性

沖縄本島の水資源の現状を見るとき，今後の水資源の開発は稀少な生物種の生息地域に及び，さらなる開発は大きな議論を呼ぶであろう．さらに新規の資源を開発することによって供給不足を解決する方向ではなく，供給を欲する消費の在り方そのものを変化させる段階に来ていると言えよう．

そこで，今後の水資源管理計画を策定する場合においては４つの柱を立てて検討することを提案したい．１）水資源の上限を明確なコンセンサスとした上で，水資源計画を前進的なものから後進的なものとし，２）その上で，水消費主体を対象として，需要の変更や節水，循環，代替，地場水資源の活用など，循環型計画の立案，実施が第二の柱となる．そして，３）地場の水資源の積極的利用，河川水，地下水の復活，景観や生態系の配慮のための流域管理が必要となり，４）それらの取り組みが地場のものであるだけに，計画段階からの市民参加が重要となる．

水資源計画が，水資源の有限性から，拡大型から保全型への転換の岐路に立つとき，様々な制約があろうが，以上のような４つの柱を念頭においた具体的な計画が今後要求されると考える．以下で各点について具体的に検討したい．

１）水資源の制約の検討

通常の将来計画の場合にはたとえば１０年後の需要の増大を予測してそれを満たすための水資源開発を行う．当然，ダムの建設コストに対する開発水量の比から，経済的なダムから開発される．ダムが連続して開発されるとき次第に経済効率は低下する．このような建設コストの増大は通常は水道料金に反映されるものであるが，沖縄の場合には建設コストのほとんどを国が負担してきたために，水道料金に反映されにくく，しかも水道法が低廉を水道供給の目的として上げているために，結果的には水道料金の上昇が需要を抑制するということにはならない．

島という制約のなかで，水資源開発量には上限があるので，本島の内部で行われる活動すべてに余裕をもって渇水を起こさず潤沢に水を供給することには限界がある．水資源の開発の責任はすべて行政に帰されてきて，水需要の無放縦な消費を助長するものであり，このようなありかたはゆきずまる構造にある．

ダム開発による水供給量について，上限はどの程度であるかを何らかの合理的な方法によって決定するこみは困難である．大半のダムが生物の宝庫である北部に集中することから，結果的には水資源開発の上限は，自然保護と開発との関係をどう調整するか，政策的な課題となる．まず県レベルで多くの利害関係者の参画のもとに上限を検討する必要がある．水資源計画，水需給計画を立案するとき，審議する構成メンバーは水資源開発を指向する行政担当者，学識経験者にかたよらず，市民代表，環境保護代表など，バランスのと

れた委員で構成される必要がある．水資源開発・水需給計画をさらに需要の内容の検討を重視する方向にシフトする必要がある．

従来のようなダムや河川からの取水を中心とする水資源開発の方法については技術者も行政も長年の豊富な経験をもつが，節水や循環，地場の水資源（たとえばこれまでの簡易水道水源のように集落の徒歩圏に存在する湧水や地下水の利用，雨水の貯留など，遠隔ではなく，消費地にある水資源を表現するために地場(local) と呼ぶ）の活用などの需要の変容を迫るような施策については，まだ緒に付いたばかりといえる．水の利用者である事業所や産業，家庭などでの内部化の努力を計ることが重要となる．

2）水資源環境保全行動計画の実施

企業や行政などの事業を行う主体に対して環境監査を実施させる世界的な潮流がある．環境監査は，事業活動がおよぼす環境影響を評価し改善するために行われるものである．生産行為から直接発生する環境影響だけでなく，製品のもたらす環境影響も含めて評価する．製品のライフサイクル，すなわち製品の原材料の採取，加工，製品の輸送，販売，消費，廃棄の各段階での環境影響を評価する．水環境への影響の評価も一つの指標である（注１）．

ここでの提案は，以上のような考えかたを沖縄の水環境に適用し，現在の水環境への影響を各事業所ごとに評価し，提出するような仕組みを作ることである．前述のバックワードの考え方を反映して，各事業者に対して，水資源環境保全行動計画を提出させるような社会的な仕組みを作りあげる．すでにある既存施設，行政，大学，ホテル，オフィスビル，大型店舗などを対象とし，現在の水環境への影響を環境監査の考えかたに基づいて評価し，どこまで削減できるかの見通しを検討する．その場合，１）どのような手段が可能か，２）それをすれば現状より水の消費量，水環境への影響が何パーセント削減できるか．３）それをいつまでに達成できるか，の行動計画の提出を求める．手段としては，二重配管による雑用水の利用や雨水利用，節水技術を取り入れることから，先進的な観光都市で行われているように，連泊客に同じタオルを使うように勧めるなど，さまざまなソフトやハードな取り組みがあろう．当然，業種によって節水や負荷の削減がし易いところ，しにくいところと差異がある．したがって一律な削減割合は設定は議論があろう．従ってその努力度が何らかの社会的な評価を受けるような仕組みも必要となる．また新設ビル，新規の事業に対しては，節水努力，負荷の削減を施設にどの程度組み込んでいるかを計画段階で事前に審査することが必要である．

また，そのような行動計画は報告書の形で，情報が市民に公開され，市民によって評価されるものであることが望ましい．

本来，生活用水の消費水量が大部分を占める沖縄では，このような取り組みが家庭をも対象とされるべきものである．各一戸ごとの家庭単位での適用は難しいにしても，上述の

考えかたを敷衍して，次項にも関連するが，地域や流域での総合的な行動計画の策定も当然行われるべきであろう．長期水需給計画が沖縄本島を一つの単位として見立てて計画されるが，ここで示す行動計画は各市町村ごと，あるいは各流域ごとに検討される必要がある．

3）流域管理の重要性

水資源問題を考える上でも，また河川の親水的，生態的な問題を考える上でも，現在の河川管理にとって重要な視点は，河川を流域として捉える見方である．

自然の仕組みからすれば，河川は流域と一体であって初めて河川である．流域が汚染されれば河川は汚れ，流域がコンクリート化されれば河川の流況も変化する．また流路だけをみても，河川は絶えず水と土の境界を通して水が出入りしており，しかもそこは生態の重要な部分であり，生物の生息の場，水質の浄化の場である．以上のような視点を忘れてしまうと，川は単なる雨水排除の側溝と何らかわりなくなる．地下水についても同様のみかたが必要である．

沖縄本島の場合，島内に約５０の河川があり，それらの流域は小さく河川の長さもいずれも小川といっていいほど短い．しかし沖縄の地場の水は都市化が進む前は，人々に情緒豊かで，豊富で，清浄な水の場を提供していた．このような水環境を取り戻すために，また前項で述べたような水環境・水資源への影響を減少させるためにも，流域全体での管理が求められている．

全国的な傾向として，三面ばりの河川の改修が，景観的にも生態的にも問題があり，多自然型工法などが推奨されるようになってきている．しかし流域管理の視点が欠ければ，三面ばりの工法を多自然型工法に変更したとしても，河川水量は減少し，水質は悪化する．これに対処するためには都市的な土地利用が占めている流域で，森林を復活させることは無理としても，家庭や事業所などの私的な土地利用にも，また公園や道路などの公共的な空間にも積極的に雨水の地下浸透を進める必要がある．また，かつて人々に潤いを与えていた湧水や地下水の水資源としての復活をはかるためにも，それらの湧水の上流では水質の保全や過度の開発に対する規制も必要となる．

河川の管理と言えば，河川を水資源採取の場として，雨水排除の場として，あるいはごくわずかであるが，親水性を確保する，生態系を保全するといった目的が設定され，それぞれの目的ごとに，行政の各部門が対応している．同じ県レベルの機関の中でもそれぞれの目的に応じて，縦割りに管理されていたり，あるいは，国，県，市町村と，いわば横割りにも分断されている．本来，河川は流域を一体として存在するものであるのに，管理の機構としては分断されている．

河川流域も地下水盆の流域も，その広がりは市町村の境界とは必ずしも一致していない点に難しさがある．そこで，流域単位で連絡協議会が要求されよう．河川の流域管理は行

政だけがするものでもないし，行政だけでできるものでもない．協議会の構成員としては前述のように，市民，行政，産業分野のそれぞれの参加が必要であり，開発と保全のバランスをとることが大切である．協議会での検討事項としては，(1)流域の水量，水質の面的な把握．(2)それらの生活，経済などの諸活動との関係の把握，(3)流域の将来計画の策定，(4)流域の行動指針の策定，(5)関係官庁，団体との連絡調整，(6)重点的な保全地区の設定，(7)市民参加の促進などがあげられよう．流域の将来計画の策定には，土地開発時に浸透係数の変化を開発前に止める，あるいは回復するなどの具体的な検討も含む．前項で述べた流域単位での循環計画もこの中に含まれる．流域管理のための県レベルでの基本的な検討が待たれる．

4）市民参加の重要性

水資源の開発について，すでにのべたようにふたつの立場がある．(1)水供給者がすべて計画し，まったく快適に供給を受けるように努力するという立場，(2)水システムと住民が関係しながら一体となって決まってくるとする立場，である．

これまでのように，資源には上限がなくいくらでも開発可能という資源の状況のもとでは前者の立場は可能であった．この場合の問題点は多々あるが，①市民は水利用についての快適性を追求するために，資源が限界に近づき，供給が不安定になると，市民は行政の責任を追求しがちである．②節水動機はまったく育成されない．③需要のコントロールがきかないために遠隔の地に水源を開発し，当該地域への負担を増大させる．④地場の資源が省みられず，地域で本来ある水資源の循環が分断あるいは喪失される．⑤渇水時に渇水被害の規模が大きくなる，などである．

上述の(2)の立場をとろうとするとき，あきらかに，行政だけで，需要を変更できるものではない．しかし，家庭や事業所，製造業など個々の利用主体がどのように節約行動をとるか，また各主体がどのような技術をとることによって節水や循環が達成されるかを考える後者の立場であっても，水利用主体に，主体ごとの利用量を割当てることを強制することもできない．

住民や個々の利用主体の節水行動を醸成することによる効果は，総量でみた水資源消費量からすると量的には，わずかかも知れない．しかし水循環が地域で根ざし，意識が高まり，あるいは潤沢な水が循環することが都市に潤いを与えることは，量的には評価できない価値を生み出す．共同で模索することの重要性，すなわち行政と主体との対立関係から協調・補完関係への移行が望まれる．

6．おわりに

本考察では今後の沖縄の水資源政策の将来を考えるために，島という有限な環境を前提

とした上で，これまで，地球環境問題の検討から提唱された人間活動の変更に関するいくつかの概念を紹介した．また，本島で見られる水資源に関する問題についてトピック的に述べたのち，今後の沖縄本島の政策として，４つの政策の柱を提言した．

実際に水資源政策に直接たずさわる方々の見方からすれば，現実の制度などの諸制約を無視した考え方であるとの批判もあろうが，今後，消費地での水利用のありかたそのものを変えることが沖縄の水政策の新たな展開をはかる上で必要であると考えるものである．

（注１）このことを産業連関表を用いて分析し，地域間での製品の授受にともなう水の地域間でのバランスを評価したWater Analysysも行われた．たとえば水源をもつＡ地域と，その水を利用して生産活動，都市活動を行うＢ地域があるとすると，水のフローはＡ地域からＢ地域へと流れるが，しかし，製品に伴う直接，間接の水消費を計量し，Ｂ地域からＡ地域へ製品が流れるとして，その製品にともなう水量を計算すると，実質的な水収支とは異なる水収支が描ける（文９）．このような考え方まで，沖縄の南北の地域間に適用し，あるいは，沖縄と県外との水収支を検討することでなんらかの政策決定の判断を行う材料とすることには無理があろう．このような水収支の考え方から，直接的にも間接的にも，沖縄の中南部の都市地域は水の圧倒的な消費地であることは言えよう．

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