THE DETERMINANTS OF GROUNDWATER EXPLOITATION IN INDIA AND OPTIMAL POLICY OPTIONS – AN INTERSTATE ANALYSIS: 1950-2000

DISSERTATION SUBMITTED TO THE JAWAHARLAL NEHRU UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

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CERTIFICATE

This is to certify that the dissertation entitled **The Determinants of Ground Water Exploitation in India and Optimal Policy Options - An Inter State Analysis: 1950-2000** submitted by **Hariprasad C.G.** in partial fulfillment of the requirements for the award of the Degree of MASTER OF PHILOSOPHY of this university is bonafide work and has not been submitted previously for any degree to this or any other university.

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Date: Hariprasad C G

dedicated to............
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Preface

The dissertation is an attempt to analyze the major determinants of ground water exploitation in India. The critical issue facing the groundwater aquifers today is that the rate of water withdrawals exceeding the long-term recharge rate, resulting in rapidly declining groundwater levels to dangerous low levels in many areas. This might result in the collapse of water channels, subsidence of soil, saline water intrusion, increasing marginal costs of extraction and etc. The problem of optimal allocation of ground water for all the users is indeed a problematic task. We pose the essence of the problem in this paper in a framework of Sole-Ownership model.

However, the problem is acute to put it in practice. Monitoring and allocation of ground water directly would have been possible if there were identical users and none is excluded. In reality neither government nor sole owner owns the ground water. Ground water is a common property concern with individual benefits and collective costs. Fragmented land – too many extractors and ill-defined property rights complicates sustainability of ground water resources. Hence indirect measures of controlling over exploitation are of immediate concern. In our experiment we try to find out the determinants of ground water extraction and propose some of the indirect methods to control over exploitation of ground water. An empirical model has been used for this purpose. The model is tested using interstate analysis of the Indian Economy for the period of 1980 – 2000. Since the model constitutes pooled (Time Series & Cross Section) data across states over the years, Panel Regression Analysis has been performed. Our empirical findings are interesting and suggestive. On the basis of our findings we thus suggest in this paper certain indirect policies for sustainability of ground water.

"If man is movement water is history If man is a people water is the world If man is alive water is life"

- Jose Manuel Serrat

El Hombre y el Agua

CHAPTER 1

INTRODUCTION

Many Renewable Natural Resources are in general common property, exploited by many people at a time. The case of groundwater among other renewable natural resources is particularly interesting because aquifers are large in geographic scope. As a consequence, it creates two types of problem, namely, first, to establish property rights over its use and secondly, to determine the efficient rate of exploitation for the aquifer as a whole.

As far as the first problem is concerned, while an aquifer is shared by many 'land holders' where over land rights are legally quite well defined, the share of aquifer underlying each land holding cannot be ascertained. Because of its very nature, the withdrawal of water by any land-holder results in a loss of water for the adjoining land-holder. Hence, it is impossible to define property rights for such reasons.

The absence of property rights as discussed above makes it difficult to treat the optimal ground water exploitation as a sole-ownership problem discussed in most text books. In fact, given the rate of regeneration, the optimal rate of exploitation can be defined only for the entire aquifers, that is, taking all the individuals as one unit. While this problem is simple, the thorny issue that involves with this is how to allocate the optimal rate for each individual. Unequal land-holdings may create the problem even more acute.

Further, assuming equitable land-holding, it may be possible to allocate certain rate of withdrawal for each land-holder but then the main problem would then be how to implement such a policy. In a situation where community participation is existing, it may be simpler to monitor the use of such a resource. However, in the absence of such participation, it may be impossible to find a monitoring agency to exercise such a policy.

According to Provencher, ground water, on the other hand is best understood to be a stock resource mined by water users. The ground water stock may increase due to natural and artificial recharge, but recharge is usually small relative to the capacity of ground water aquifer, and so often its variability is not a significant consideration in the allocation decision. Given the natural constancy of ground water resource, clearly a primary consideration in the joint use of surface water and ground water is the role the ground water resource as a contingent source of water; the ground water serves to buffer seasonal revenues against the vicissitudes of surface water supply (Daniel W. Bromley, 1995).

Implicit in the concern about the conjunctive use of surface water and ground water is the belief – prominent among resource economists – that in the absence of government intervention the ground water is misallocated. Put another way, discussions about the role of government in ground water management must begin with an understanding of the consequences of doing nothing.

In our study, we attempt to analyze the major determinants of ground water exploitation in India. The critical issue facing the groundwater aquifers today is that the rate of water withdrawals exceeding the long-term recharge rate, resulting in rapidly declining groundwater levels in many areas. As a renewable but exhaustible resource, ground water follows a typical path of accumulation and unless a well planned exploitation is followed, aquifers will be pushed to dangerous low levels. The case of ground water, among other natural resources, is particularly interesting because important aquifers are large in geographic scope and its users are many. The unregulated extraction[1] rate will be 'too high' if it results in the water table drawn down 'too low', causing extraction costs to be 'too high'. Over the years, due to indiscriminate extraction of

[1] The word extraction is synonymously used as harvesting, draft, withdrawal, exploitation or abstraction.

ground water[2] in most of the states in India, water tables have been depleted to a dangerously low level in many places. Depletion of an aquifer has three chief economic effects. First, an aquifer can become 'extinct' through overuse if its geology is such that water channels that feed the aquifer can collapse as water table goes down and in consequence the aquifers eventually become dry. Second, water in the ground is "money in the bank" for use in periods of drought when local rains fail and surface water courses dry up. Third, it is that extraction costs rise as the water table falls[3]. Even if the social benefit of the water exceeds extraction cost, the latter will be economically excessive under an uncontrolled regime. The purpose of the aquifer management is to control these costs and optimize water use over time. Depleting ground water levels pose threat of salinity and further it can be an environmental catastrophe as it disturbs the hydrological cycle[4].

We treat the optimal ground water exploitation as a sole-ownership problem discussed in most text books. We try to explain the nature of state variable, stock of water and control variable, harvesting. Using Hamiltonian, as a convention, we will solve for the sole owner's objective function with respect to a dynamic constraint. Further, we will address the problem under two regimes – controlled and uncontrolled, wherein we try to understand how controlled regime works and how far it is a betterment over uncontrolled regime and hence the benefit of the former for sustainable harvesting of ground water resources. We will also try to understand how policy variables such as taxes and permits to control indiscriminate harvesting would work.

The problem of optimal allocation of ground water for all the users is indeed a problematic task. The problem is acute to put it in practice. Monitoring and allocation of ground water directly would have been possible if there were identical users and none is excluded. In reality neither government nor sole owner owns the ground water. Ground

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[2] See section 4.1 in Chapter 4 for details.
[3] Also called as *User Cost.*
[4] Apart from a major and reliable source for water supply, groundwater also plays an important role in moderating and modulating the surface water regime and surface eco-systems.

water is a common property concern with individual benefits and collective costs. Fragmented land – too many extractors and ill-defined property rights complicates sustainability of ground water resources. Hence indirect measures of controlling over exploitation are of immediate concern. In our experiment we try to find out the determinants of ground water extraction and propose some of the indirect methods to control over exploitation of ground water. We are interested in using an empirical model for this purpose. We set up a regression model to test the variation in extraction to be explained by certain policy variables which are also the determinants of ground water extraction. The model will be tested using interstate analysis of the Indian Economy for the period of 1980 – 2000. Since the model constitutes pooled (Time Series & Cross Section) data across states over the years, Panel Regression Analysis will be performed. On the basis of our findings we suggest in this dissertation certain indirect policies for sustainability of ground water.

We organize the dissertation in the following way: In section 2, we review the literature. In Section 3, we discuss the meaning of optimal rate of ground water harvesting in a sole-ownership model framework. In Section 4, we discuss the key factors determining ground water extraction which would lay grounds for our empirical studies. In Section 4, we set up the basic model of our regression analysis in the context of the Indian economy. In Section 5, we discuss our major empirical findings. In Section 6, we draw some broad conclusions and major policy suggestions for sustainable development of ground water resources.

CHAPTER 2

LITERATURE SURVEY

The survival of all forms of life on earth depends on the availability of water. Supply of this key natural resource in acceptable quality, and adequate quantity, and at the required place and time, is of utmost importance, whether in the world's megacities or in a tiny human settlement in a remote mountain area (Kanchan Chopra, 2003).

As an integral part of the land-water interactive cycle, groundwater is largely an invisible resource, occurring in a range of water producing geological structures either as free flowing artesian water or as confined or unconfined, static or dynamic resource. Apart from a major and reliable source for water supply, groundwater also plays an important role in moderating and modulating the surface water regime and surface eco-systems. Any comprehensive basin-wise approach to water resources development, therefore, needs to address sub-surface water dynamics well in advance, as a prelude to a sustainable and integrated water development plan.

India occupies about 2.45% of terrestrial surface of the earth and receives about 4% of the global precipitation, i.e., it receives a mean annual precipitation of 1170 mm, making a total average annual precipitation of about 4000 cu km in the form of both rain and snow [National Commission on Integrated Water Resource Development Plan (NCIWRDP), 1999]. Of the total annual average precipitation of about 4000 cu km received by India, roughly 33.3% evaporates and 44.5% flows as surface water. Of the balance 22.2%, 12% remains as a naturally replenishable stock in the form of soil moisture and the remaining 10% as groundwater reserves, in the deeper pores of permeable and weathered soil and fissures in hard rocks. This part of precipitation, which percolates into the bedrock, is the available recharge. Geologic structure, porosity, permeability and transmissivity of soils and rocks, and localized variations in formation thickness and petrology, influence the renewability and potential for groundwater development.

The annual rechargeable dynamic groundwater potential for India is estimated by the NCIWRDP (1999) at 432 cu km and by the World Bank (1999) at 452 cu km. About half of which belong to the geo-hydrological setup of the Ganges – Brahmaputra – Meghna basin. Dynamic groundwater aquifers exist in these areas at shallow depths of only 5-15 meters. On account of the significance of groundwater in rising agricultural yields, its role as a catalyst of rural development as well as in poverty alleviation cannot be underplayed. Of paramount importance to most of the rural population, groundwater plays a critical role in maintaining agricultural production during spells of drought; it serves 45 % of the irrigated area in the country, and is responsible for increasing agricultural output by 40 %(World Bank, 1999b). One of the major advantages of storing water in underground aquifers is that it can be stored for years, with little or no evaporation loss, to be used in drought years as a supplementary source of water supply. It also has the advantage that storage can be near or directly under the point of use and is immediately available, through pumping, on demand. The tubewell revolution that has swept through agriculture capitalizes on these advantages. For example, crop yields under tubewell irrigation in India are frequently two to three times greater than crop yields from irrigation by canal systems alone. Another great advantage of groundwater is that as water slowly percolates down into the aquifer it is usually purified of biological pollutants. Thus, groundwater is usually the best source of drinking water, especially in rural areas of developing countries where water treatment facilities are not available.

Shallow aquifers are recharged by local percolation of surface water and discharged by (especially deep-rooted) trees that “pump” the water out of the ground and transpire it into the air. But the great aquifers of the world run deep and are recharged by rain and melting snow from mountains. Sometimes these are hundreds of miles away from points of use.

2.1 Economics of Ground Water:

Groundwater is analytically similar to biological resources such as fish because the water is rechargeable as the fish are reproducible. But unlike fish, the recharge rate of the water is not biological. The recharge rate is usually modeled as if it were not at all stock dependent. In this sense, the water is like minerals or gas in the ground. But unlike these, the natural growth (recharge) rate is not zero. Modeling ground water serves specially two purposes. First, the case of groundwater provides an opportunity to expose the common property problem in its purest form: the "common pool" problem. Second, this is another natural place to use a cost function which is derived from, the production function. The common pool problem begins with the simple idea that the efficient intertemporal (dynamic) allocation of resources requires that any decision on the current rate of use take into account the entailments for future supplies (Neher, 1990) and future demands. The first transferable implication is that a marginal user cost is associated with mining groundwater, reflecting the opportunity cost associated with the unavailability in the future of any unit of water used in the present. The marginal extraction cost[1] would rise over time as the water table fell. Pumping would stop either when (1) the water table ran dry or (2) when the marginal cost of pumping was either greater than marginal benefit of the water or greater than the marginal cost of acquiring water from some other sources (Tom Tietenberg, 1996).

Until the Supreme Court judgment in *M.C.Mehta v Union of India,* the Union government was of the view that central legislation may not be permissible since 'Water' was a state subject under Schedule VII of the Constitution. Each state would need to introduce separate legislation to regulate and control ground water resources and to assist the states, a model bill was circulated in 1970. The Supreme Court, however, expressed a *prima facie* that Article 253 of the Constitution and the provisions of the Environment (Protection) Act of 1986 (EPA) empowered the Centre to regulate ground water exploitation. The court's observations were made on an application filed by M.C. Mehta

[1] The cost of pumping the last unit to the surface.

urging the Central Government to constitute a national authority under section 3(3) of the EPA to ensure that ground water resources are managed sustainably. Noting the recommendations made by the National Environment Engineering Research Institute, Nagpur, the Supreme Court directed the Union Ministry of Environment and Forests to constitute the **Central Ground Water Board** (CGWB) as an authority under section 3(3) of the EPA to regulate the indiscriminate exploitation of underground water in the country (Shyam Divan et al, 2001).

2.2 Measurement of Ground Water Recharge:

With the establishment of state-wise ground water investigation organizations since 1971, data on water fluctuations began to be compiled, thereby permitting recourse to water level fluctuation instead of rainfall approach to ground water recharge. In this direct method rise in water table in sample observation wells in an area during the main monsoon period is the basis for estimating volume of ground water recharge. Multiplying this vertical rise by the area or a track, say, a block, one obtains the estimated volume of soil/earth in whose pores and empty spaces (e g, fractures in rocks) is stored the ground water recharge from rainfall, canal seepage, etc. multiplying this volume by 'specific yield' factor (a sort of measure for the relative volume of water to the total volume of wet soil/earth), once end up with the final measure of ground water recharge (Dhawan, 1990).

2.3 Misuse and/or Overuse of Ground Water:

In many parts of India, industry, agriculturists and municipalities are increasing their dependence on groundwater resources. For the user this is an attractive option since the source is continuous (unlike monsoon-fed rivers and streams), the water is generally clean and the user need not depend on an external agency for the supply. The rights to the groundwater attach to the land and hence land owners may draw on the ground water and use it as if it were their private property. According to Chhatrapati Singh this private ownership regime is inequitable because it leaves out all the landless and tribals who do not enjoy private ownership (Singh, 1990).

Since the exploitation of ground water has a bearing on the user's fundamental right to life under Article 21 of the Constitution, his or her right to dig bore wells cannot be restricted by an executive fiat. This right may be restricted or regulated only by an Act of the legislature (Puttappa H. Talavar, 1998). Rasbid Faruqee and Yusuf A. Choudhry[2] stressed for the national water policy to set the ground rules for allocation to different users, water rights, pricing, and environmental safety. There is no national statute regulating ground water resources and apart from Gujarat none of the states have legislated in this field[3].

The need for good management of ground water resources was recognized earlier by the Kerala High Court in a public interest litigation filed by local islanders seeking to protect fresh water resources on the Lakshadweep islands. The petitioners apprehended that the government scheme to pump out ground water on the island would cause saline intrusions in the fresh water table which would, in turn, imperil the potable water supply on the islands. The Kerala High Court commissioned an expert report which opposed the government scheme. Recognizing the importance of fresh water to the islanders and holding that the right to fresh water was an aspect of the fundamental right of life, the High Court prohibited the government from implementing the scheme until it was reviewed and modified by the union Ministry of Environment and the Ministry of Science and Technology (Attakoya Thangal, 1990).

The citizens of Karaikudi town in Tamil Nadu challenged a government scheme which would carry waters from an ancient spring named Sambai Uthu which was the principal source of water for the town from time immemorial. In 1987, the municipality of Karaikudi unanimously opposed the scheme which was intended to benefit Tirupattur.

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[2] The World Bank Report, South Asia, 2001.

[3] The Gujarat amendments to the Bombay Irrigation Act introduced a licensing procedure for sinking tube wells and prohibited the sinking of tube wells beyond a depth of 45 meters.

In the face of this opposition the state government suspended the scheme. Seven years later the government revived the project leading to a public outcry and allegations that the project was being hurried through to benefit a mineral water factory at Tirupattur. The High Court later directed the state government to review the scheme after taking into consideration the availability of ground water and also the views of the residents of Karaikudi (Pazha Karuppaih, 1997).

Decline in water tables and resulting ground water scarcity is also referred to the 1985-1988 drought years. But there is, in fact, much evidence of a long-term decline in water in most areas of Gujarat; while the downward trend has a tendency to accelerate during droughts, it is not confined to drought years alone. For instance, a simple regression of water level on time for the period 1981-90 brings out a declining trend in 87 out of 96 observation wells used by CGWB (Ahmedabad) in its assessment of recent trends in water tables. The total decline of this 10-year period, calculated for each well on the basis of the observed time trend, is larger than 4 meters for nearly 50 per cent of these wells (Bela Bhatia, 1992).

Land owners pumping ground water can sell excess water to other farmers/ users has been highlighted and this as a practical means of overcoming high costs of installing pumps and hence allows economies of scale; allowing access to groundwater for poor and marginal farmers. Some evidence suggests that privately sold water is more productively employed than from state schemes. This type of water selling is in wide use in India particularly since Green Revolution (Bhatia, 1986).

Paddy sown area has special significance insofar as the ground water balance in Punjab is concerned. Irrigation requirements of HYV paddy are much higher than wheat, cotton and other kharif crops. Paddy cultivation picked up in Punjab after 1973, particularly in traditionally non-paddy growing low-rainfall districts. It appeared that all those districts which allocate a higher proportion of the gross cropped area to paddy are also the ones with negative ground water balance (Surendar Singh, 1991).

In the absence of plant cover, the run-off rate is accelerated. In Gujarat, denudation has played an important role in accelerating run-off and reducing ground water recharge. Just as denudation is a cause of increasing water scarcity, the disruption of the hydrological cycle itself contributes to the disappearance of forests. The latter problem should be a cause of deep concern in its own right (Bela Bhatia, 1992).

The groundwater use has been a major factor in the growth of agricultural production over the past two decades. Groundwater tubewells not only supply additional water but also have provided flexibility to match canal water supplies with crop water requirements. Before 1960s the development of the groundwater tubewells was limited to open dug wells operated by animal power mostly outside the canal command areas. Large-scale development of groundwater resources was first attempted by the govt. under salinity control and reclamation projects for controlling waterlogging and salinity (The World Bank staff appraisal report for Pakistan, 2001).

C.H. Hanumantha Rao and V. Ratna Reddy in their 'Watershed Development in India-Recent Experience and Emerging Issues' and 'Sustainable Watershed Management' (EPW, Nov 4, 2000) respectively, stressed for efficient watershed management to make groundwater economically viable, socially acceptable and ecologically sustainable. They have attempted to lay the theoretical ground for a detailed and rigorous empirical work through collective action theories.

Madhya Pradesh Water Sector, Restructuring Project (ESA Report, 2001) points out the improper exploitation of groundwater. In many of the sub basins there has been over exploitation of groundwater resources. Some of the taluks have been declared as distressed (Malwa Plateau). There are reports of seasonal rise in the water table levels at many locations.

World Bank project for Kerala points out the problem of undulating topography with steep gradients, the rivers flow into the sea within hours after precipitation. And there is considerable variation in the available/utilizable groundwater resources between the districts and between the blocks within a district due to natural variations in topography, the hydrogeology, the pattern of rainfall and the groundwater draft. The per capita water resources are less than that of many other dry states of India.

In many arid and semi-arid regions groundwater has been withdrawn at rates far in excess of recharge, leading to groundwater mining, declined major water level, increased pumping costs and decreased well yields. Overexploitation anywhere is often accompanied by detrimental environmental side effects, such as land subsidence, water-quality degradation, and reduces groundwater discharge to springs, streams and wetlands. During the past 2 decades, the water level in several parts of the country has been falling rapidly due to the indiscriminate increase in wells drilled for irrigation of both food and commercial crops. India's rapidly raising population and changing lifestyles have also increased the domestic need for water. Intense competition from users – agriculture, industry, and domestic sectors – is driving the groundwater table lower. Rural people on India derive 80% of their domestic requirements from groundwater, whereas about 50% of the urban and industrial supplies are drawn from ground sources (World Bank, 1999b).

The extraction of water from aquifers in some districts of India (North Gujarat, Southern Rajasthan, Saurashtra, Coimbatore and Madurai Districts in Tamil Nadu, Kolar District in Karnataka, and the whole of Rayalasema Region in Andhra Pradesh) exceeds recharge by a factor of two or more. As these aquifers are depleted, the resulting cutbacks in irrigation could reduce India's harvest by 25 percent or more (Seckler et al. 1998, and Shah 1993). 'Groundwater levels in the Pishin Lara Basin, Pakistan have steadily declined approximately 2 meters per year since 1987. In China, groundwater levels are declining almost everywhere there is pump irrigation. Under much of the north China Plain, where nearly 40 percent of China's grain is harvested, water levels are dropping roughly 1.5 meters per year' (World watch Institute, 1999).

Groundwater depletion also has serious equity implications since falling water tables take the resource out of reach of small and marginal farmers. Falling water tables can make wells for domestic water supply run dry. An especially dangerous aspect of falling groundwater tables is illustrated in Bangladesh, where toxic levels of arsenic are being found in the drinking water of millions of people. One theory is that falling groundwater tables have permitted oxidization and mobilizations of natural deposits of arsenic in these areas. Other important problems of groundwater storage are water quality, the cost of pumping to extract groundwater, and the recoverable fraction of recharge.

2.4 Efforts to Harvest Rain Water, Urban Hydrology, Measures to Increase Ground Water Recharge:

The work done under deep drilling for ground water exploration in Ganga Basin till November, 2001 are as follows:-

i. A revised work plan for deep exploration of ground water in the foothills of Himalayas was prepared to incorporate the 'Bid for Deep Exploration in Ganga Basin, Uttaranchal and Uttar Pradesh.

ii. To study the recharge prospect in deeper aquifers, a Morpho-hydrogeological study is being continued in Gaula Watershed in Kumaon Himalayas. The various morphometric parameters and area of sub-watersheds were calculated. Analysis of the data is under progress.

iii. Mapping of Siwalik Formations continued in between the Main Boundary Fault and Himalayan Frontal Fault to know its tectonic setup and the recharge possibilities of deep Siwalik aquifers underlying the Ganga Alluvial Plains. The work is still in progress.

iv. Various basin & lithology-wise data for the report on 'Deep Aquifers of India' were compiled (Groundwater statistics, 2001).

The works done under the project till November, 2001 in West Bengal are as follows:-

i. A report on Evaluation of Performance of various Arsenic Removal Equipments installed in Arsenic affected areas of West Bengal was finalized, on the basis of work that was carried out in collaboration with The United Nations Industrial Development organization. The work was subsequently presented in a Workshop entitled "Arsenic mitigation Search for Sustainable Solution" organized by UNIDO.

ii. Arsenic content of some selected food items (60) was determined.

iii. Hydrogeological test (3) was carried out to assess the impact of pumping in arseniferous aquifer.

iv. Heavy metal analysis of arsenic rich water was completed (70 samples).

v. 18 samples were analyzed to ascertain the efficacy of different filters by filtering arsenic rich water through them at a controlled rate.

vi. Evaluation of different filters (3 nos.) by filtering arsenic rich water of the same concentration (1.7 mg/l) was carried out.

vii. An arsenic mitigation cell was established within the Chemical Laboratory of CGWB, ER.

viii. A project proposal for the propagation of Pteris Vittata -a fern absorbing arsenic, to regulate Arsenic Sludge is under formulation, which will be carried out in collaboration Botany Dept. of Kalyani University.

ix. A project proposal for construction of piezometers, for monitoring arsenic contamination, utilization in Arsenic affected areas of parts of West Bengal and Bihar has been approved.

x. Arsenic Atlases is under preparation - depiction of arsenic concentration in different blocks indicating depth wise variation of arsenic in North 24 Parganas and total Chemistry.

xi. Arsenic free aquifers have been identified and wells have been completed in four different sites by way of ground water exploration (R&D Project – West Bengal, 2001[4]).

The coastal tract of Orissa is traversed by numerous creeks led by tidal rivers like Matei, Salandi and Baitarani. It is observed that tidal water from these rivers flows into

[4] R & D project studies in respect oh high incidence of arsenic in Ground Water of West Bengal.

the creeks twice a day. The tidal water in the creeks remains fresh up to the middle of March and subsequently as the flow in the rivers is reduced. Water becomes saline due to tidal action which remains up to June. The creeks Haldiganda, Karangi, Nuanai, Kaudia, Badaharipur in Bhadrak district, Kaninai in Kendrapara dist. and Talsuan in Puri dist. were identified for arresting saline ingress through ground water recharge (R&D Project - Orissa, 2001[5]).

The Rajiv Gandhi National Ground Water Research and Training Institute (RGNGWR & TI) started functioning from Raipur in May 1996. The institute is being established with the aim of starting training courses, seminars, symposia etc., at national as well as international level and provides research facilities in the field of ground water in India (Groundwater statistics, 2001).

The Board brings out a quarterly journal, 'BHUJAL NEWS".A numbers of scientific papers on relevant matters were contributed by scientists of Central Ground Water Board and from other organizations. The journal contains various technical notes, news items, list of published papers and unpublished reports of the Board etc. The journal is being dispatched to Central and State Agencies, State/Public Sector, Undertakings and academic institutions. During 2001-2002,till November,2001,the Bhujal News issue Volume 14,No-3&4, 15, No-1&2, No-3&4 have been released (Bhujal News, 2001).

2.5 Pollution of Ground Water:

Indiscriminate disposal of urban and industrial wastes, excess application of fertilizers cause infiltration of toxic elements in the aquifer system and produced contamination. Studies to assess nature of pollution, sources of pollution and measures to control ground water pollution have been given a much higher priority during the IX[th] Plan. During 2001- 2002,21 pollution studies were taken up. During 2001-2002 (up to January,2002) ground water pollution studies have been initiated in the following areas –

[5] R & D Project Studies in respect of arresting salinity ingress through Ground Water Recharge in Orissa.

Nawashahar & Hoshiarpur(Punjab), Parwanoo (H.P), Ambala & Panchkula (Haryana), Osmanabad, Ballarpur paper industry, Zarud & Warud area (Maharashtra), Khalidabad Industrial Area, Basti district & Dewa block of Barabanki district (U.P.), Margherita Coal field area(Assam), Boden block, Nuapara district (Orissa), Hyderabad Metropoletan Area (A.P.), Manali area of North Chennai (T.N.) and around Villappisala, Trivandrum district (Kerala). Studies have also been undertaken in the fluoride affected area of Nagaon district, Assam. Samples were collected and analyzed which indicate high concentration of fluoride in Ground Water (Ground Water Pollution Studies, 2001).

Responding to a public interest litigation alleging failure and neglect by the state in providing safe drinking water to villages in Mandla district, a division bench of the Madhya Pradesh High Court directed the state to extend free medical treatment and compensation to the effected persons. Water drawn from hand pumps sunk by the state contained excessive fluoride which caused bone diseases, deformities and dental fluorosis (Hamid Khan, 1997).

In January, 1996 an expert committee appointed by the Gujarat High Court Submitted its report on pollution caused by Gujarat fluorochemicals Ltd. (GFL) in the Panchamahals district. Several residents of the villages neighbouring GFL complained of crop failures, health problems and a loss of milk production. The report (a model of sound methodology and clear analysis) records that most water samples drawn from tubewells indicated fluoride and chloride concentrations exceeding potable water limits. *Prima facie,* GFL appeared to be responsible for the adverse environmental impact (Gupta, 1996).

Binani Zinc Ltd. was directed by the Kerala High Court to supply drinking water to the affected villagers after test samples drawn from neighbouring wells were found to contain 'acidic' water unfit for drinking. The water contained very high concentration of zinc, cadmium and total dissolved solids which may have been caused by seepages from the factory (Edayar Environment Protection Council, 1997).

A study conducted by a team of *Down to Earth* reporters in 1999 found that numerous factories deliberately inject untreated effluents into the ground, contaminating underground aquifers. Samples drawn from eight sites in Haryana, Gujarat and Andhra Pradesh, showed traces of heavy metals like iron and zinc in all samples, cadmium in five samples and lead in three. All the samples contained dangerously high levels of mercury, known to cause Minamata disease, neurological disorders, retardation of growth in children and abortion. M. Tiwari & R. Mahapatra reported that the Central Ground Water Authority and the state pollution control boards were completely ineffective in checking polluters.

Special studies on urban hydrogeology are being undertaken with the objective of having sustainable water supply to the major cities affected by water supply and pollution problems. During the course of studies, it has been proposed to look into various development in such urban centers so as to make ground water based supplies to these cities sustainable for 21st century. During 2001-2002, 15 studies were initiated in the cities of Udhampur (J&K), Shimla (H.P.), Patiala (Punjab), Gwalior City (M.P.), Raipur City (Chhattisgarh), Kolhapur (Maharashtra), Allahabad (U.P.), Gaya City (Bihar), Calcutta Municipal Corporation area (W.B.), Jorhat (Assam), Balasore town (Orissa), Eluru & Warangal (A.P.), Mysore City (Karnataka) and Chennai City (T.N.). Premonsoon work, monitoring work with data analysis, preparation of hydro geological maps, collection of water samples have been completed for above studies (Groundwater statistics, 2001).

2.6 Need for National Policy for Sustainable Water Use:

Following guidelines of the National Water Policy, the ground water resource estimation was being revised to GEC'97 methodology[6]. Meetings are being held with State Government Organizations to make joint assessment of ground water resources.

[6] Earlier estimation of ground water resource of the entire country was based on 'GEC'84'.

The States of Uttar Pradesh, Tamil Nadu, Gujarat Rajasthan and Kerala have completed the exercise for entire state. The states of Maharashtra and Orissa are in the final stages of completion of the exercise.

Working models of the Hydrological cycle, Conjunctive Use of Surface and Ground Water, Artificial Recharge Studies carried out in JNU, New Delhi, Rotary Drilling Rig, Photos of drilling activities, Panels (4 no. of Size 2'x6') showing activities and achievements of CGWB, Translite showing various methods of Artificial Recharge, Translite of Roof Top Rain Water Harvesting Techniques and various Publications released by the CGWB were displayed to create awareness on various aspects of ground water development and management. In addition to this on the spot analysis of water to check its suitability for drinking &domestic use, testing kit and treatment techniques for high fluoride were also displayed through the R &D lab of CHQ, Faridabad (Ground Water Statistics, 2001).

The CGWB has taken up experimental artificial recharge studies in Karnataka and Maharashtra, and operational research projects in NCT of Delhi. The scheme is being implemented in cooperation with State Governments, Jawaharlal Nehru University and Indian Institute of Technology, Delhi. The estimated cost of the scheme is Rs. 3.67 crore. During 1994-95, investigations were taken up for selection of suitable sites for various structures for artificial recharge in the above areas. The State agencies for construction of artificial recharge structures were identified and design and cost estimates were finalized. During 1995-96, five cement plugs have been constructed in Amaravati district and two percolation tanks and one injection well with two observation wells have been constructed in Jalgaon district in Maharashtra. Design and cost estimates for conversion of existing minor irrigation tanks to percolation tanks, construction of two percolation tanks, five cement plugs, two recharge shafts and one nala diversion in Maharashtra have been approved by the Technical Coordination Committee. In Karnataka, watershed treatment in Gauribidanur taluk, Kolar district has been completed and five recharge well fields have been constructed. In Jawaharlal Nehru University in Delhi, sites for two check dams have been identified. Construction of one check dam is likely to start shortly and design and cost estimates in respect of the other check dams are under consideration. Two injection wells have been constructed in Third Campus area for roof top rain water harvesting. A proposal for rain water harvesting in Technical Teacher's Training Institute in Chandigarh is being formulated. Special studies on urban hydrogeology are being undertaken with the objective of having sustainable water supply to the major cities affected by water supply and pollution problems. During the course of studies, it has been proposed to look into various developments in urban centers so as to make ground water based supplies to these cities sustainable for 21st century. During 2001-2002, 15 studies were initiated in the cities of Udhampur (J&K), Shimla (H.P.), Patiala (Punjab), Gwalior City (M.P.), Raipur City (Chhattisgarh), Kolhapur (Maharashtra), Allahabad (U.P.), Gaya City (Bihar), Calcutta Municipal Corporation area (W.B.), Jorhat (Assam), Balasore town (Orissa), Eluru & Warangal (A.P.), Mysore City (Karnataka) and Chennai City (T.N.). Premonsoon work, monitoring work with data analysis, preparation of hydro geological maps, collection of water samples have been completed for above studies. Working models of the Hydrological cycle, Conjunctive Use of Surface and Ground Water, Artificial Recharge Studies carried out in JNU, New Delhi, Rotary Drilling Rig. Photos of drilling activities, Panels (4 no. of Size 2'x6') showing activities and achievements of CGWB, Translite showing various methods of Artificial Recharge, Translite of Roof Top Rain Water Harvesting Techniques and various Publications released by the CGWB were displayed to create awareness on various aspects of ground water development and management (Groundwater Statistics, 2002).

A large number of econometric studies of water use have been conducted in United States. Hanemann (1998) summarizes the theoretical underpinnings of water demand modeling and reviews a number of determinants of water demand in major economic sectors. Useful summaries of econometric studies of water demand can be found in Boland et al. (1984). Dziegielewski et al. (2002b) reviewed a number of studies of aggregated sectoral and regional demand. A substantial body of work on model structure and estimation methods was performed by the USGS as stated in Helsel and

Hirsch, 1992 (*Committee on USGS Water Resources Research, National Research Council, 2002*). The committee also analyzed the structure of the 1980–1995 state-level data from the NWUIP by multiple regression analysis in order to determine if aggregate water use could be correlated with routinely collected demographic, economic, and climatic data.

CHAPTER 3

OPTIMAL RATE OF GROUND WATER HARVESTING: A SOLE OWNER MODEL

Many renewable resources are intergenerational common pools, exploited by one generation after another. The case of groundwater among other natural resources is particularly interesting because important aquifers are large in geographic scope and its users are many. The problem with groundwater has been basically regarded as the 'common pool problem' which begins with the simple idea of the efficient intertemporal allocation of resources which requires that any decision on the current rate of use takes into account the entailments for future supplies and future demands. The critical issue facing the groundwater aquifer today is that the rate of groundwater extraction exceeding long term recharge rate, resulting in rapidly declining groundwater levels in many areas (Dhawan. B.D, 1972, 1980, 1990, 1991). The groundwater stock may increase due to natural and artificial recharge, but recharge is usually small relation to the capacity of groundwater aquifer, and so often its variability is not a significant consideration in the allocation decision.

In this chapter we try to understand the nature of optimal allocation of groundwater in dynamic programming framework. Also we try to understand the nature of stock variable (Groundwater) and control variable (either Extraction or Efforts to extract) and accordingly the government's (assumed to be the sole owner) role in the sustainable development of groundwater resources. The objective function of the sole owner is to maximize net benefit with respect to Dynamic Constraint, given the conditions of Maximum Principle and Port-folio Balance. For the sustainable development of groundwater resources, monitoring groundwater extraction becomes foremost task of the government.

3.1 Nature of Ground Water – Production Function:

In chapter 1 we made an argument in support of the assumption of sole owner for formulation of theoretical model for optimal ground water allocation. Smooth changes are made for mathematical ease wherever it is required. Following, let the objective of a management authority be to maximize the present value of net social benefit. The net benefit is defined as (gross) benefits (B) minus costs (C). Benefits increase with extraction/ harvesting (h), but at a decreasing rate. That is,

$$B = B(h); \qquad B'(h) > 0; \qquad B''(h) < 0 \qquad (1)$$

These benefits are illustrated in the upper panel of Figure 1 by the curve labeled "B".

Harvesting has a cost, which is a function of the rate of harvest, h, and the stock of ground water, x. The resource stock x is called 'state variable' in a dynamic setting. With x momentarily fixed, extraction h and effort, E are uniquely related by the production function,

$$h = F(x)E \qquad (2)$$

with positive but diminishing marginal values of $F(x)$, that is,

$$F'(x) > 0, \qquad F''(x) < 0 \qquad (3)$$

Note, however, that the marginal and average products of E are the same and equal to $F(x)$.

The cost of extraction depends on the rate of extraction (h) and the stock of water (x):

$$C = C(h, x) \qquad (4)$$

This cost function is also represented in the upper panel of Figure 1. It is the solid line labeled "*C*" and it is drawn for some constant *x*. It shows marginal cost rising

$$\left.\begin{aligned} &C_h > 0 \\ &\text{and at an increasing rate} \\ &C_{hh} > 0 \end{aligned}\right\} \tag{5}$$

That is marginal cost increases with output in the usual way. Also, extraction cost decreases as *x* increases, that is,

$$\left.\begin{aligned} &C_x < 0 \\ &\text{and given } h, \\ &C_{xx} > 0 \end{aligned}\right\} \tag{6}$$

These cost reduction relationships can be seen in the lower panel of Figure 1 where cost is calculated for some given *h*. Cost declines with *x* but at a decreasing rate (the curve becomes less steep).

To simplify, let

$$C = wE \tag{7}$$

where *w* is returns to efforts and then from (2)

$$E = \frac{h}{F(x)} \tag{8}$$

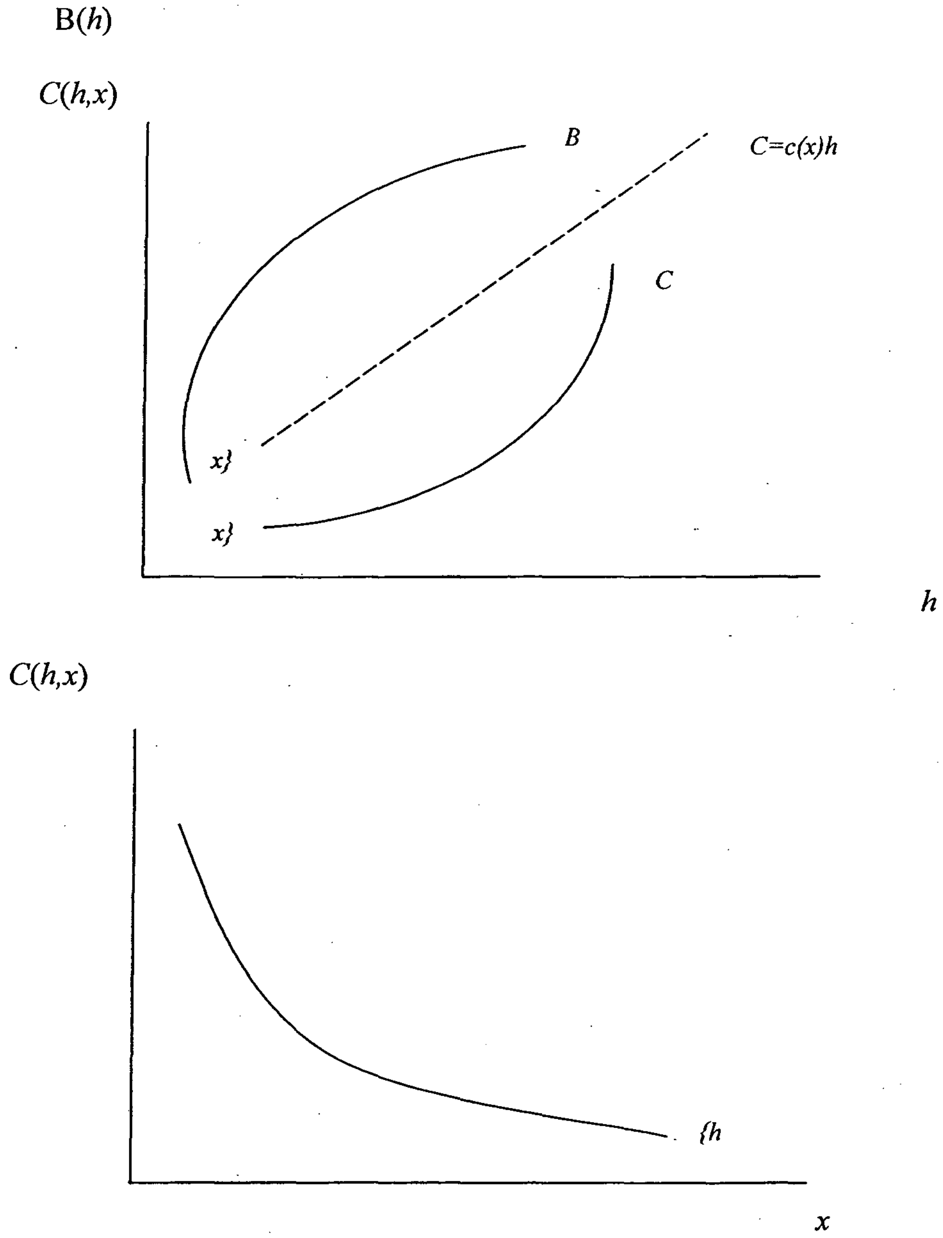

Figure 1 Social Cost and benefit functions

Then

$$C(h, x) = \frac{w}{F(x)}h$$

implying average cost to be $\dfrac{C(h,x)}{h} = \dfrac{w}{F(x)}$

Clearly,

$$C_h = \frac{C}{h} = \frac{w}{F(x)}$$

So marginal and average costs are equal, that is

$$c(x) = \frac{w}{F(x)}$$

So that $\Big\}$ (9)

$$C = c(x)h$$

This is shown by the straight dashed line labeled "*C*" in Figure 1. Now let us see how average (equals marginal) costs depend on *x*.

Total cost, $C(h, x) = \dfrac{w}{F(x)}h$

Then, $C_x = -\dfrac{wF'(x)}{F(x)^2}h$ (10)

So $C_x < 0$ since $F'(x) > 0$. Also

$$C_{xx} = -w\frac{F(x)^2F''(x) - 2F(x)F'(x)^2}{F(x)^4}h \quad (11)$$

So $C_{xx} > 0$ since $F''(x) < 0$. Also, since

$$c(x) = c'(x) = \frac{C(h,x)}{h}, \quad (12)$$

it is clear that these conditions apply to *c*(x) as well.

3.2 Objective Function of Sole Owner:

Now, it is straightforward to set up the water authority's planning problem,

$$MAX\, V = \int_0^T (B(h) - c(x)h)e^{-rt}dt. \qquad (13)$$

This is subject to the dynamic constraint that the stock, *x*, grows at a constant natural rate *G* but is depleted by extraction (*h*). So, *V* is maximized

$$\text{S.T. } \dot{x} = G - h \qquad (14)$$

To start with the dynamic constraint[1], the natural growth (recharge) rate is modeled as exogenously determined and constant at *G*. It is not stock dependant. Of course, as an aquifer becomes "nearly full," it develops "leaks" to the surface through springs and by augmenting streams and rivers. Where *G* is the exogenous recharge rate[2] and *h* is the flow rate of extraction. The aquifer loses volume, and the water table falls if *h* exceeds *G*, reducing *x* $(dx/dt = \dot{x} < 0)$.

3.3 The Discount Rate:

Note that a discount rate[3] (*r*) appears in *V*. The discount rate could be positive to reflect the fact that local water authorities do typically work with positive discount rates. The effects of positive discounting on water tables, and on the cost of extraction, will become evident as we proceed further.

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[1] This defines the motion of *x* over time as the difference between natural growth and the extraction rate. It can be thought of as "nature's own budget constraint".
[2] Usually measured in Million Hectare Meter or Million Cubic Meter per unit of time i.e., one year in India
[3] Three groups of thoughts namely, A. Harberger, Marglin & Martin Feldstein, and P. Diamond & Ronald McKean have analyzed fundamental conceptual understanding of the discount rate. For details see: Richard W. Tresch, 'Public Finance – A Normative Theory', II Edition, Academic Press, USA, Page 731-757, 2002.

The integrand represents discounted (at rate *r*) net of *V*. the discount factor applied to *V* at each time is *exp(-rt)*. There is portfolio balance (PB)[4] if x competes with other assets in the economy by yielding a zero net profit at the margin: Gross profit from holding the asset, minus the opportunity cost doing so, equals zero. In this problem, the portfolio balance condition must recognize that the other assets in the economy earn r so that the opportunity cost of holding x units resource is rxq.

Here we take the risk of defining a new function (L) for mathematical ease, which takes into account accrued changes in the value of the water level. We write,

'The present value of Aquifer' = λx.

Here λ is the shadow price of the resource (Conrad, J.M & Clark, C.W, 1989)[5] (the shadow price is sometimes called co-state variable since it is used to value the state variable x). It is the resource price, q, (user cost) that is to be discovered.

The aquifer changes in value if its quantity or price changes:

$$\frac{d}{dt}(\lambda x) = \lambda \dot{x} + x \dot{\lambda}. \tag{15}$$

Add the value of these accruals to V to form the new L function:

$$L = \int_0^T [(B(h) - c(x(h)e^{-rt} + \lambda \dot{x} + x \dot{\lambda}]\, dt \tag{16}$$

The first order conditions are found by maximizing L with respect to (h, x), with the dynamic constraint being used to substitute out the $\dot{x}$. To maximize an integral, maximize each term, at every time, that it contains. (Each term for each time is added together with the other terms that form the sum.) In this case, each term in the sum is represented by V plus changes in asset value. These are contained in the square brackets surrounding the integrand of L. this is to be maximized with respect to (h, x), with the dynamic constraint.

---

[4] There is PB if the natural asset b is competitive with other assets in the economy that earn a representative rate of return (r).

[5] Conrad, J.M & Clark, C.W, *Natural Resource Economics: Notes and Problems*, 1989, p. 15 (λ explicitly reflects the influence of *h (control variable)* on the change in the *x (state variable)*. If an increase in h_t reduces the amount of variable x_{t+1} then λ reflects an intertemporal cost, often referred to as *user cost.)*.

$$\underset{\{h,x\}}{MAX}[(B(h)-c(x)h)e^{-rt}+\lambda\dot{x}+x\dot{\lambda}]$$

$$\text{S.T. } \dot{x}=G-h \qquad (16)$$

3.4 The Hamiltonian:

Before doing this it is conventional to define

$$H=[B(h)-c(x)h\,e^{-rt}-\lambda\,\dot{x}]. \qquad (17)$$

H is called *Hamiltonian*[6] function. It is interpreted as *performance indicator* for the ground water industry. It is the sum of two terms:

$H = V +$ the value of physical investment.

Physical investment is $\dot{x}$, and this is valued at the shadow resource price λ.

As a performance indicator, the Hamiltonian function (H) gives a 'snapshot' idea of how a program is doing at a point in time. Of course, V counts as a currently generated benefit because of access to the resource. But rents can be 'too high' if current depletion is 'too great'. Future rents can be depressed if the resource stock is currently depleted. And future rents count, along with current rents in the objective functional. This consideration for future V is captured by the investment terms. A snapshot performance audit would calculate the Hamiltonian function.

Using the Hamiltonian, the problem is written

$$\underset{\{h,x\}}{MAX}[H+x\dot{\lambda}], \qquad H=[B(h)-c(x)h\,e^{-rt}-\lambda\,\dot{x}]$$

$$\text{S.T. } \dot{x}=G-h \qquad (18)$$

The First Order Conditions (FOCs) are necessary conditions for the optimal solution. They are found in the usual way.

$$H_h=0 \qquad (19)$$

and

[6] The Concept of Modern control theory.

$$H_x + \dot{\lambda} = 0 \qquad \text{or} \qquad \dot{\lambda} = -H_x. \qquad (20)$$

Also note that

$$H_\lambda = \dot{x} \qquad (21)$$

This last equation ensures that the dynamic constraint is always in force. Taken together, these three steps reveal conditions that necessarily characterize an optimal program. These conditions are known as Maximum Principle (MP)[7], the Portfolio Balance (PB)[8] condition, and the Dynamic Constraint (DC)[9].

Substituting the expression for $\dot{x}$ into H,

$$H = [B(h) - c(x)h\, e^{-rt} - \lambda\,(G - h)]$$

$$H = [B(h) - c(x)h - \lambda\ e^{rt}(G - h)]\ e^{-rt} \qquad (22)$$

Apply the MP noting that *exp(-rt)* is just a discount factor:

$$H_h = B'(h) - c(x) - \lambda\, e^{rt} = 0$$

$$\lambda\, e^{rt} = B'(h) - c(x).$$

It will simplify notations, and assist interpretations, if a new shadow price is defined:

$$q = \lambda\, e^{rt}$$

Hence, with h as the control, and x as the state variable, they are

(MP) $\qquad q = B'(h) - c(x).$

The resource price is the difference between the (marginal) benefits and (the marginal equals average) costs of using h. The resource stock (x) has value because it can generate a net (marginal) benefit in excess of (marginal equals average) extraction costs. (MP) can also be written

$$B'(h) - q = c(x). \qquad (23)$$

The left side of the equation is unit marginal benefits *net* of the unit depletion charge. Next, the portfolio balance condition must be satisfied.

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[7] This ensures that h is properly chosen, no matter what the level of x, so that the net value of the marginal product of h equals the price for it (or marginal cost equals price).
[8] Ibid 4.
[9] Ibid 1.

Referring to the new shadow price $q = \lambda e^{rt}$, with $r > 0$, one can think of λ as the *present value shadow price* and of q as the present value price (λ) *capitalized forward* at the rate r. This defines q as the *current value shadow price.* 'Current value' is taken to mean the value that is currently applied at any time, present or future.

For $r > 0$, at $t = 0$,

$$q(0) = \lambda(0).$$

However, for any t,

$$\lambda = qe^{-rt}.$$

In this view, λ is the current value shadow price (q) *discounted backward* at the rate r.

Going back to H,

$$H = [B(h) - c(x)h\, e^{-rt} - \lambda(G - h)] \qquad (24)$$

Portfolio Balance requires

$$\dot{\lambda} = -H_x = hc'(x)\, e^{-rt} - \lambda G'$$

Using,

$$q = \lambda e^{rt},$$

the two shadow prices move together through time according to

$$\dot{q} = \lambda(r)e^{rt} + e^{rt}\dot{\lambda}$$

$$= r\lambda e^{rt} + e^{rt}\dot{\lambda}$$

$$\dot{q} = rq + e^{rt}\dot{\lambda}$$

Substituting from above for $\dot{\lambda}$,

$$\dot{q} = rq + e^{rt}(hc'(x)\, e^{-rt} - \lambda G')$$

$$= rq + (hc'(x) - \lambda\, e^{rt}G')$$

$$= rq + hc'(x) - qG'$$

$$\dot{q} = (r - G')q + hc'(x)$$

(PB) $\qquad \dot{q} = rq + hc'(x) \qquad$ (Since x is constant, $G' = 0$) $\qquad$ (25)

The resource price must rise at the rate of interest (Hotelling's rule[10]) except to the extent that the resource contributes (marginally) to current performance as measured by the current value Hamiltonian, [ ]. Since $c'(x)$ is negative, the planner will be in portfolio balance for $\dot{q}/q < r$. Finally,

(DC) $\dot{x} = G - h$ (26)

governs the motion of the water stock.

3.5 Motion of the Function:

The equations of motion follow from reducing equations (19), (20), and (21), three necessary conditions to two differential equations in either *(q, x)* or *(h, x)*. There is not much to choose on convenience grounds in this case, but the synthesized solution (in *h, x*) has some special appeal because it can guide the water authority in terms of observable variables: Both the pumping rate and the "water table" are, in principle, observable while the resource price is not.

To find the synthesized solution, it is first necessary to use (MP) to purge $\dot{q}$ and q from (PB). The expression for q is already in hand. From (MP)

$$q = B'(h) - c(x).$$

Differentiate this with respect to time to find $\dot{q}$:

$$\dot{q} = B''(h)\,\dot{h} - c'(x)\,\dot{x}.$$

The (DC) is an expression for $\dot{x}$ in terms of h. Substitute this in

$$\dot{q} = B''(h)\,\dot{h} - c'(x)(G - h).$$

[10] One (manager) is indifferent toward the alternatives of holding the resource in the ground or extracting and selling it if the expected proportional rate of capital gains equals the rate of interest on alternative assets. The condition of indifference applies to all individuals that seek to maximize income and wealth. So the condition is an equilibrium condition for suppliers to the market for the extracted product. Similarly the demanders are also in equilibrium as their willing to pay $\dot{p}/p = r$. It is known as *Hotelling's rule* for pricing a resource that is strictly limited in supply.

Substituting this for $\dot{q}$ into (PB), along with (MP) for q, yields, after simplifying,

$$B''(h)\,\dot{h} = r[B'(h) - c(x)] + Gc'(x). \tag{27}$$

This equation, along with (DC)

$$\dot{x} = G - h,$$

is the synthesized dynamic system of necessary conditions (Equations 8, 9 , 10) for optimal management of the aquifer. Note that these equations are in the form

$$\dot{h} = f(h, x) \tag{28}$$

$$\dot{x} = g(h, x). \tag{29}$$

It happens that g_x is zero, so graphic depiction of stock dynamics is immediate: $\dot{x} = 0$ for $h=G$; $\dot{x} > 0$ for $h < G$; $\dot{x} < 0$ for $h > G$. The stock of water is stationary if extraction equals the natural recharge rate.

To describe the dynamics of h it is more direct to differentiate the $\dot{h}$ equation with respect to $\dot{h}$, h, and x, then solve for the slope of the (h, x) relation (dh/dbx for the steady state of h so that $d\dot{h} = 0$. Begin with

$$B''(h)\,\dot{h} = r[B'(h) - c(x)] + Gc'(x).$$

Differentiating with $B''(h)$ held constant,

$$\begin{aligned} B''(h)d\dot{h} &= r[B''(h)\,dh - c'(x)\,dx] + Gc''(x)\,dx \\ &= rB''(h)\,dh - [rc'(x) - Gc''(x)]\,dx. \end{aligned} \tag{30}$$

In the steady state of h, $\dot{h}$ is constant at zero. So $d\dot{h}=0$ there.

$$0 = rB''(h)\,dh - [rc'(x) - Gc''(x)]\,dx. \tag{31}$$

Solving for the slope of the $\dot{h} = 0$ *line*,

$$\frac{dh}{dx} = \frac{rc'(x) - Gc''(x)}{rB''(h)}.$$

Recalling that $c'(x) < 0$, $c''(x) > 0$, and $B''(h) < 0$,

$$\frac{dh}{dx} > 0.$$

Moreover, it is easy to see that

$$\frac{d\dot{h}}{dx} < 0, \quad \frac{d\dot{h}}{dh} > 0, \tag{32}$$

which indicate motions of the $\dot{x} = 0$ line.

Both the $\dot{x} = 0$ and the $\dot{h} = 0$ lines are plotted in Figure 1(a). Motions of these curves

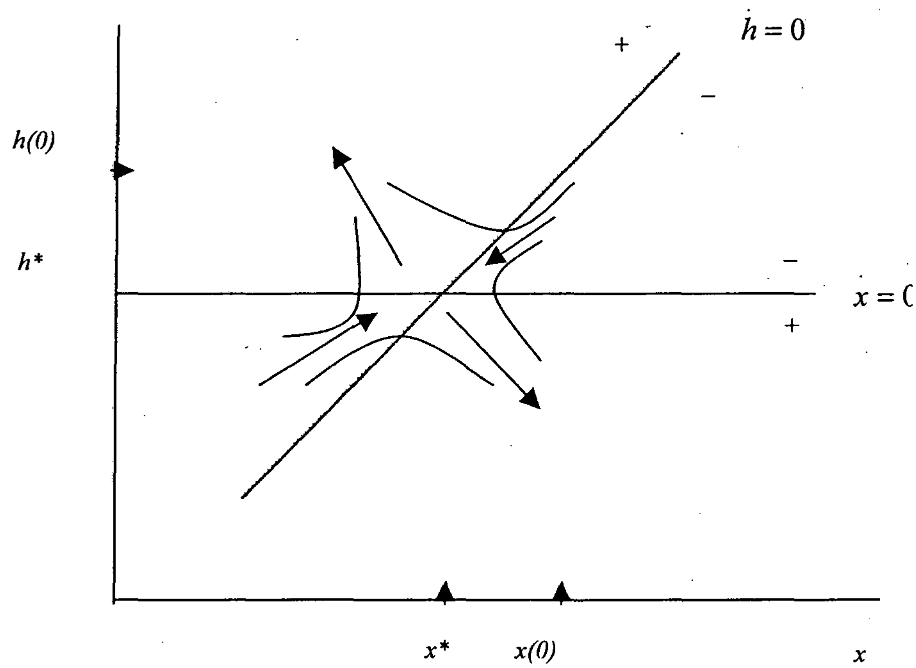

Figure 2 The synthesized solution in (*h*, *x*) for the aquifer.

are also indicated. It is clear from the indicated motions that long-run planning will carry the aquifer to (h^*, x^*) along one of the stable arms. For example, if $x_0 > x^*$, the strategy is to set the initial x equal to $h(0) > h^* = G$ and 'mine' the aquifer at first, being careful to *reduce* the pumping rate as the water table *falls*.

3.6 A Case – *r* is Zero:

It is important to see the role that the discount rate (r) plays here. If r was zero, then V would be maximized in the long run by pumping the recharge (h=G) of a 'nearly full' aquifer. This can be seen by imagining a steady state in which $r = 0$ and $h = G$. Then,

$$V = \int_0^T (B(G) - c(x)G]dt. \tag{33}$$

Recall the $c(x)$ is smaller if x is greater. V is the greatest for the largest possible x, for then pumping costs are the smallest amount possible. So x^* is less than the largest possible amount only because the positive discount rate compels 'impatience', to reap benefits 'up front'. Hence, the initial 'mining' of the resource at the expense of subsequently higher pumping costs.

3.7 A Comparison – Controlled and Uncontrolled Regimes:

How does this optimal profile of extraction compare with the one predicted if pumping is controlled, if the aquifer is exploited as a common-property resource? Without a defensible theory of disequilibrium for a common-property regime, it is impossible to compare entire profiles. But it is possible to compare steady states ($\dot{h} = \dot{q} = \dot{x} = 0$) with $h = G$ in both regimes. For the controlled aquifer,

$$C(x^*) = B'(G) - q$$

$$q = -\frac{hc'(x^*)}{r}. \tag{35}$$

The common-property aquifer can be simulated by assuming that either $q = 0$ *or* that $r = +\infty$. One can reason that independent, non-cooperating exploiters will place no value on the resource because no one can own or control it. Alternatively, one might suppose that the aggregation of common-property extractors behave *as if* they were central planners who valued the future not at all. In either case, for the steady state

$$c(\hat{x}) = B'(G)$$

$$q = 0 \tag{36}$$

for the common-property resource ($\hat{x}$). As expected, $c(x^*) < c(\hat{x})$ and $x^* > \hat{x}$. The planned aquifer fields $h = G$ at lower cost because it contains more water (the water table is higher).

3.8 An Alternative within Controlled Regime – Taxes and Permits:

Still, there are cases where some form of management is either clearly appropriate, or politically expedient. In this light, it is worthwhile to consider alternatives to central control namely, control by local districts, severance tax and a permit (quotas) system.

'Compared with a single, centralized regulator, the district units of control would prove more responsive to changing economic and hydrologic conditions and more capable of obtaining the production and cost information necessary to make the appropriate allocative decisions' (Daniel W. Bromley, 1995).

The disadvantage of local control is that in a so far as a small number of independent entities extract ground water from a common aquifer, the potential still exists for inefficient use of the resource. With each local district considering the marginal user cost that its (collective) pumping imposes on its members, and ignoring the marginal user cost that it's pumping imposes on non-members.

It is natural to wonder if large aquifers having many decentralized users can be effectively regulated to avoid uneconomic depletion. Both theoretical and institutional considerations must be taken together. The model suggests that a severance tax per unit of extracted resource (a 'water rate' = t) levied at the rate of q per unit of water would do the job. If this were done, the individual users would

$$\underset{\{h\}}{MAX}\; B(h) - c(\bar{x}) - th \tag{37}$$

where h is the individual rate of extraction and $\bar{x}$ is the resource stock commonly exogenous to all users. It is easy to see that the tax will lead users to maximize their net benefits where

$$B'(G) - t = c(\bar{x}) \qquad (38)$$

in the steady state for all the users taken together. This replicates (MP) so that $\bar{x} = x^*$. The tax rate would have to be adjusted so that extraction falls (t rises) as the resource declines toward x^*.

The other alternative is a system of tradable pumping permits in which the regulator determines a minimum ground water stock x^*, and allocates among individuals corresponding to the difference between the initial (current) stock level and x^*. In essence, each individual's bundle of permits represents its private stock of ground water. This private stock declines due to ground water pumping and increases to reflect the individual's share of periodic recharge. It also changes in response to the individual's activity in the market for ground water stock permits, increasing when permits are purchased and decreasing when permits are sold. Hence, marketable quotas (permits) could be used, lowering the aggregate toward $h^* = G$ as x falls toward x^*. Note, however, that quotas aggregating to G will hold *any* steady state. If h (the sum of quotas) equals G (the recharge rate), then $\dot{x} = 0$ for any x. So care must be taken that

$$r[B'(G) - c(x)G] = -Gc'(x) \qquad (39)$$

solves for x^*. Then conditions required by (MP) and (DC) for the steady state are satisfied.

Enforcement of either taxes or quotas poses problems when many users are scattered over a large geographic area. Taxes paid on day-to-day usage are less easy for the public to monitor. And, whereas tax evasion can be viewed as cheating the government, poaching water over quota is more likely to be viewed as cheating one's neighbor. Moreover, the neighbor could have knowledge, from public records, of who holds what quotas. The permit system is economically inefficient as the pumping cost externality and the risk externality persist after the allocation of permits. Still quota regime is more capable than others as marketable quotas are a property right and so are registrable.

3.9 Conclusion:

However, where extraction is the responsibility of public agencies, or large private utilities, these could easily be assigned (marketable) quotas and could, in turn, charge appropriate water rates to ultimate users. Whichever method is used, the management authority ideally should have jurisdiction over the geographic area occupied by the aquifer. For large aquifers, administration of this scope can be cumbersome and costly. Moreover, aquifers are often transnational or extend across jurisdictions that are constitutionally sovereign under federal systems. Notwithstanding these difficulties, the rising resource price *(q)* on water in depleting aquifers suggests undertaking more costly regulatory procedures and innovative thinking about new interjurisdictional institutions.

CHAPTER 4

DETERMINANTS OF GROUND WATER EXPLOITATION: AN EMPIRICAL STUDY

Monitoring and allocation of ground water directly would have been possible if there were identical users and none is excluded. In reality neither government nor sole owner owns the ground water. Ground water is a common property concern with individual benefits and collective costs. Fragmented land – too many extractors and 'ill-defined property rights'[1] complicate the meaning of sustainability of ground water resources. Hence indirect measures of controlling over exploitation are of immediate concern. X^* in Figure 2 is the target point given point in time. The indirect macro economic forces like taxes, permits, subsidies, crop pattern, provision for more surface water irrigation, and afforestation are to be modulated in order to achieve the goal.

In this chapter we discuss the key factors determining ground water extraction which would lay grounds for our empirical studies. We flip through the source of the model and findings in brief. We discuss the reasons for internalisation of the model which would suit Indian economic structure and accordingly we specify the model. Finally, we run through the sources of information and data wherein we briefly understand the nature and components of the variables, and sources of data for each variable.

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[1] Land based water allocation policy has been adopted in many states of India (Northwest India). The basic concept of this policy is that water right accrues from land ownership. It is recognized that every farmer has the right to receive water proportional to his land holding irrespective of the size of land holding. This practice has led the indiscriminate withdrawals of ground water, as it is available on free of cost (Dhillon et al, 1988).

4.1 Determinants of Ground Water Extraction: A Regression Analysis

In spite of the practical problem associated with direct observation over the ground water exploitation, it is not inconceivable to control exploitation by indirect measures. If we know the causes of exploitation we can explain how to control extraction accordingly with the policy variables concerned. Policies like ban of rice production in water scarce area, and encouraging alternative policies like dry farming, poultry farming, cattle farming etc., can be suggested. For this purpose, we set up a regression model in the next section.

A number of factors, though finite, are responsible for ground water extraction. They can be classified broadly into four.

1 Growth factors – Population and GDP

Growth factors such as population, urbanization, construction activities, and overall resulting growth indicators have strong impact on increased water demand over the years. Population has been rapidly increasing over the years which has increased the demand for water making the per capita availability of water per year to decline rapidly, and projected per capita availability for 2025 alarms the WATER STRESS as it falls below 1700 cu m per year. Overcrowding in cities causing deforestation, slum, lack of initiation in waste water management, high pace of industrialization have all together contributed to the contamination of ground water. The solid, liquid and gaseous waste that is generated, if not treated properly, results in pollution of the environment; this affects in contamination of ground water too due to the hydraulic connectivity of 'hydraulic cycle'. Changing lifestyles have also led to the depletion of GW. Construction of buildings, roads, dams etc. would require large amount of water. It also has the advantage that storage can be near or directly under the point of use and is immediately available, through pumping, on demand. This has led to the indiscriminate ground water exploitation at zero cost due to lack of proper function of pricing system. Growth is referred to as all economic activities in an economy. By nature of dynamism, Indian economy has experienced economic expansion due to growing economic needs. This can be foreseen with the help of growth indicators such as GDP, PCI, SDP, and etc.

2 Production Structure: Agriculture and Forestry

The water level in several parts of the country has been falling rapidly due to the indiscriminate increase in wells drilled for irrigation of both food and commercial crops. Advent of "Green Revolution" had also led to the depletion of ground water. To put it straight, green revolution is due to ground water. With the use of HYV seeds and fertilizer all the more water is required for the maturity of crops. Green revolution was characterized by land-saving but water-using technologies whereas dryland areas needed water-saving enterprise and practices which optimize output per unit of scarce water. In the absence of such technologies, the farmers in the dryland areas go in for water-intensive crops like rice when water resources are conserved giving rise to conflicts on water and scarcity of drinking water.

The rapid increase in the agro-chemical use in the past 5 decades has contributed significantly to the pollution rose from less than 1 million tones in 1948 to a maximum of 75 million tones in 1990 (CSE, 1999). This has resulted in the contamination of ground water. Hence water resources have been rendered unsafe for human consumption as well as for other activities such as irrigation and industrial needs. This illustrates that degraded water quality can in effect contribute to water scarcity as it limits its availability for both human use and the eco-systems, further it exacerbates the extraction which is an instant cause of increased demand out of scarcity. And finally plantation of forests (afforestation), maintenance of zoo, etc, are all of immediate concern which would require lots of watering leading to extraction.

3 Property Rights – Pricing System

Land based water allocation policy has been adopted in many states of India (Northwest India). The basic concept of this policy is that water right accrues from land ownership. It is recognized that every farmer has the right to receive water proportional to his land holding irrespective of the size of land holding. This practice has led the indiscriminate withdrawals of ground water, as it is available on free of cost. Movement of ground water towards steeper aquifers has posed severe threat to the property rights assignment as the whole process remains unnoticed. Due to the absence of property rights or ill-defined property rights, the economic value of the harvested resource is not accrued to the aquifers.

4 Govt. Policies – Taxes and Subsidies

Ground water extraction by pumping is indirectly encouraged through subsidies for fuel and electricity. Pricing electricity at a flat rate or even supplying it free instead of on a 'volumetric approach' has led to the over exploitation of scarce ground water resources. Rural and urban water charges are much lower than the cost of provision and suffer from poor operation and maintenance. The result in all sectors has been higher consumption and inefficient cost recovery. According to Bhatia, other forms of agricultural subsidies also have led to clearing of forests causing free rainfall runoffs directly to the sea and precluding precipitation, percolation, seepage into ground water recharge/storage.

4.2 The Empirical Model: Cross – State Panel Study

Considering interstate primary and secondary data for the Indian economy, our interest is to see how interstate differences in extraction are responsible for depletion of ground water. For this exercise, the use of multiple regression analysis under single equation regression models is of immense interest. Panel data analysis will be performed as the regression study is on across states over the years.

Methodology is very much similar to the one used in '*Estimating water use in the US: A new paradigm for the national water use information program, Committee on USGS Water Resources Research, National Research Council, 2002*'. A substantial body of work on model structure and estimation methods was performed by the United States Geological Survey (USGS) as stated in Helsel and Hirsch, 1992. Here public water supply including both ground water and surface water is modeled as a function of a set of explanatory variables. The regression estimated by Helsel and Hirsch is given below.

$$PS_{it} = a_0 + b_1\,AP_{it} + b_2\,GP_{it} + b_3\,R_{it} + b_4\,T_{it} + b_5\,LG_{it} + b_6\,LS_{it} + a_iS_i + b_iT_iD_i + \varepsilon_{it}$$

PS_{it} =	per capita withdrawal (gallons per day) in state *i* during year *t*
AP_{it} =	average price in constant 1995 dollars
GP_{it} =	gross state product per capita in constant 1995 dollars
R_{it} =	total summer season precipitation in inches
T_{it} =	average summer temperature, degrees Fahrenheit
LG_{it} =	indicator for state groundwater law system (equals 1 if prior appropriation, 0 otherwise)
LS_{it} =	indicator for state surface water law system (equals 1 if prior appropriation, 0 otherwise)
a_i =	intercept adjustor for individual states
S_i =	indicator for individual states (equals 1 if the state is included in the model, 0 otherwise)
b_i =	trend coefficient describing changes in withdrawals in gpcd per year for individual states
D_i =	indicator for state-specific trend (equals 1 gpd if the state is included in the model, 0 gpd otherwise)

Findings of the model are as follow;

Dependent/Explanatory Variable	Regression Coefficient	*t*-Ratio	*F*-value Probability
Intercept (gpcd)	115.881	3.28	0.0012
Average price of water ($/1,000 gal., real 1995 dollars)	-7.779	-2.63	0.0091
Gross State Product per capita ($1,000, real 1995 dollars)	1.676	3.22	0.0015
Precipitation in summer months (May to Sept., in inches)	-2.119	-4.02	0.0001
Average temperature during summer (Fahrenheit degrees)	0.983	2.15	0.0326
Indicator of states with prior appropriation groundwater rights system	29.136	3.05	0.0027
Indicator of states with prior appropriation surface water rights system	17.218	1.81	0.0716
NOTES: Mean water use = 183.7 gpcd; n = 192; R^2 = 0.52; mean APE = 12.9%; root MSE = 31.6 gpcd.			

The size and signs of the estimated regression coefficients fall within the ranges of expected values. For the purpose of the study of local condition of Indian states, inclusion and exclusion of appropriate variables are accordingly done. Depending on the purpose for which the estimates are used, the dependent variable (i.e., extraction) can be presented in different ways. For example, in studies of surface and groundwater resources, the data are usually available as yearly withdrawals at a point such as a river intake or a well. Because the water withdrawn is typically used (or applied) over a larger land area, an equivalent hydrologic definition of water use would be the use of water over a defined geographical area (e.g., an urban area, a county, or a state). Total water use within a larger geographical area such as a country or state can be presented as a sum of water use by several groups of users within a number of sub areas.

Generally, water use at any level of aggregation can be modeled as a function of one or more explanatory variables.

$$E_{it} = \alpha_i + \sum_j \beta_j X^j_{it} + \varepsilon_{it} \qquad (1)$$

Where E_{it} represents extraction within geographical area i during year t, X^j is a set of j explanatory variables, which are expected to explain variation in extraction, and ε_{it} is a random error term. The coefficients α_i and β_j can be estimated by fitting a multiple regression model to the historical data.

4.3 Model Estimation:

An estimate of groundwater withdrawals for any state and year can be made using the model (1). The variables are chosen in a way that the government can bring in policy implications accordingly with the results. As yet, extraction as a function of variables like rainfall, temperature, precipitation, evaporation, permeability, geologic structures and etc, are considered to be exogenous and hence are not included in the model.

Helsel and Hirsch's model considers total water supply including both ground water and surface water. Fortunately, there exists an efficient property right system for both the sources of water supply and the federal system is the sole supplier of water. Hence it is modeled as a function of mainly average price and SDP. But in case of India, due to the absence of efficient property rights (even ill-defined) system, the concept of sole owner is jolted. Ground water is zero priced. Hence we are interested to check in the true conditions (local) which would explain ground water extraction in India. Following, we model our dependent variable as

$$Extraction_{it} = \alpha_i + \beta_1\, Agriculture_{it} + \beta_2\, Canal\ Irrigation_{it} + \beta_3\, Subsidies_{it} + \beta_4\, Forest\ Cover_{it} + \beta_5\, Population\ Density_{it} + \varepsilon_{it} \quad (2)$$

Where,

$Extraction_{it}$	Ground Water Withdrawal (mhm) in state i during t
$Agriculture_{it}$	Share of Agricultural product in State Domestic Product in state i during t at 1993-94 prices
$Canal\ IR_{it}$	Area Irrigated by Canal Irrigation in State i during t
$Subsidies_{it}$	State Agricultural Subsidies in i state during t
$Forest_{it}$	Actual Forest Area in Square Km in State i during t
$Pop\ Density_{it}$	Population Density in State i during t

4.4 Sources of Information and Data:

For the purpose of modeling, we explore the structure of the past Central Ground water Board (CGWB) state-level aggregated groundwater use data, based on corresponding (and routinely collected) demographic, economic, and climatic data. The purpose of this inquiry is to determine if multiple regression models have the potential to explain the temporal and geographic variability across India of the aggregated groundwater use estimates produced by the CGWB. According to the availability of data on all the required variables 14 states[2] have been chosen for the years from 1988 – 2000 with 4 years internal gap[3].

Variables	Components	1988-89	1992-93	1996-97	2000-01
Extraction	Gross Draft in MCM (Irrigation+Domestic+Industrial)	1988-89	1992-93	1996-97	2000-01
Source: Ground Water Statiatics, CGWB, Ministry of Water Resources, Faridabad					
Agriculture	Agri/SDP in 1993-94 Prices	1988-89	1992-93	1996-97	2000-01
Source: Statistical Abstract of India					
Canal Irrigation	Area Irrigated in Hectares	1988-89	1992-93	1996-97	2000-01
Source: Statistical Abstract of India					
Subsidies	Fertilizer+ Power+ Irrigation	1988-89	1992-93	1995-96	Extrapolated
Source: Acharya, S. S, (2000), 'Subsidies in Indian Agriculture and their Beneficiaries', Agricultural Situation in India, Volume LVII, August, Number 5, pp 251-260 (Library, Directorate of Economics & Statistics, Ministry of Agriculture)					
Forest Cover	Area in Sq.Km	1989	1993	1997	1999
Source: State of Forest Report 2001, Forest Survey of India, Ministry of Environment and Forest.					
Population Density	Pop per Sq.Km	1998	1992	1996	2000
Source: Statistical Abstract of India					

[2] Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal (See Appendix 1 for details).
[3] Cross state analysis for the years 1988, 1992, 1996 and 2000.

CHAPTER 5

ANALYSIS OF RESULTS

5.1 What is expected from Regression?

Ground water extraction is mainly due to agriculture. Gross area irrigated by tube wells, dug wells and other wells over the years has increased in most of the states. Irrigation accounts for nearly 90% of total extraction. The water level in several parts of the country has been falling rapidly due to the indiscriminate increase in wells drilled for irrigation of both food and commercial crops. Advent of "Green Revolution" had also led to the depletion of ground water. To put it straight, green revolution is rather due to ground water. With the use of HYV seeds and fertilizer all the more water is required for the maturity of crops. Green revolution was characterized by land-saving but water-using technologies whereas dryland areas needed water-saving enterprise and practices which optimize output per unit of scarce water. In the absence of such technologies, the farmers in the dryland areas go in for water-intensive crops like rice when water resources are conserved giving rise to conflicts on water and scarcity of drinking water. The rapid increase in the agro-chemical use in the past 5 decades has contributed significantly to the pollution of ground water[1]. This has resulted in the contamination of ground water. Hence water resources have been rendered unsafe for human consumption as well as for other activities such as irrigation and industrial needs. This illustrates that degraded water quality can in effect contribute to water scarcity as it limits its availability for both human use and the eco-systems, Further it exacerbates the extraction which is an instant cause of increased demand out of scarcity. By nature, canal water is near substitute to ground water. More the area irrigated by canal water, lesser the ground water extraction. Subsidies which have been under consideration are specifically agricultural subsidies. They constitute a sum of fertilizer subsidy and electricity subsidy. They are basically

[1] Usage of agro-chemicals rose from less than 1 million tones in 1948 to a maximum of 75 million tones in 1990 (CSE, 1999).

input subsidies. For instance, provision of free electricity or even charging at a flat rate has been a state policy in most of the states. More the subsidy more is the extraction. Before expecting the sign of the forest coefficient, we would want to distinguish between national and plantation forests. Generally, forests help recharging the ground water aquifers. In the absence of plant cover, the run-off rate is accelerated. 'In Gujarat, denudation has played an important role in accelerating run-off and reducing ground water recharge. Just as denudation is a cause of increasing water scarcity, the disruption of the hydrological cycle itself contributes to the disappearance of forests. The latter problem should be a cause of deep concern in its own right' (Bela Bhatia, 1992). An increased forest cover would support higher recharge resulting in an increase in the water tables. Increased water table is associated with low cost of extraction. Hence forest cover and extraction are expected to move together. Further, in an effort to keep the environmental balance, most of the state governments have resorted to protect the forest areas and plantation of forest (afforestation), maintenance of zoo, etc, are all of immediate concern which would require lots of watering leading to extraction. Population density has strong impact on increased water demand over the years. Population has been rapidly increasing over the years which has increased the demand for water making the per capita availability of water per year to decline rapidly, and projected per capita availability for 2025 alarms the 'WATER STRESS' as it falls below 1700 cu m[2] per year.

[2] Seckler et al. 1998, Sustainability Development Index.

5.2 Fixed Effects Vs Random Effects:

Method	Fixed Effect			Random Effect		
Variables	Coefficients	t	P>ItI	Coefficients	z	P>ItI
Constant	-24024.95	-3.59	0.001	173.5732	0.03	0.973
Agriculture	4958.95	1.29	0.205	5438.728	1.04	0.296
Canal IR	-0.1135907	-0.13	0.899	2.272487	1.98	0.047
Subsidies	1.31742	4.36	0.000	1.286212	3.14	0.002
Forest Cover	1.035361	5.19	0.000	0.1248539	1.86	0.063
Pop Density	14.41316	2.92	0.006	16.4506	2.74	0.006
	Number of Observations = 56					
	Number of Groups = 14					
	R-Sq:	Within	0.6917	R-Sq:	Within	0.4908
		Between	0.026		Between	0.3605
		Overall	0.0271		Overall	0.3599
	F(5,37)	16.61		Wald Chi-Sq	38.39	
	P>F	0.0000		P > Chi-Sq	0.000	
	Corr(Ui, Xb)	-0.937		Corr(Ui, X)	0	
				RE Ui	Gaussian	
	Sigma u	33964.737		Sigma u	5638.1689	
	sigma e	1143.3073		sigma e	1143.3073	
	rho	0.99886818		rho	0.96050436	

5.3 Hausman Specification Test:

Coefficients			
Extraction	Fixed Effects	Random Effects	Difference
Agriculture	4958.95	5438.728	-479.778
Canal IR	-0.1135907	2.272487	-2.386078
Subsidies	1.31742	1.286212	0.0312079
Forest Cover	1.035361	0.1248539	0.9105068
Pop Density	14.41316	16.4506	-2.037433

Test: Ho: difference in coefficients not systematic

chi2(5) = (b-B)'[S^(-1)](b-B), S = (S_fe - S_re)

= 23.51

Prob>chi2 = 0.0003

5.4 Breusch and Pagan Lagrangian Multiplier Test for Random Effects:

extrn[state,t] = Xb + u[state] + e[state,t]

Estimated results:		
	Variance	sd = sqrt(Var)
Extraction	1.38e+08	11732.49
e	1307152	1143.307
u	3.18e+07	5638.169

Test: Var(u) = 0

chi2(1) = 35.62

Prob > chi2 = 0.0000

- Based on Hausman specification test, we obtain the test statistic of 23.51, which far exceeds the 95 % critical value for Chi – Squared with 5 degrees of freedom, 1.145476.

- Based on least squares residuals, we obtain Lagrange Multiplier test statistic of 35.62, which far exceeds the 95 % critical value for Chi – Squared with 1 degree of freedom, 0.00393.

At this point, from both the tests, we conclude that the classical regression model with a single constant term is inappropriate for these data. The result of the tests in both the cases is to reject the null hypothesis in favour of random effects model.

5.5 Analysis of Results: Fixed Effects Model

The size and signs of the estimated regression coefficients fall within the range of expected values. These coefficients can be interpreted to mean that across India (14 states), from 1988-2000, the mean withdrawal was 16511.52 Million Cubic Meters (MCM) from the data. This average withdrawal would -

- Increase by 4958.95 MCM if the share of agriculture in SDP were increased by Rs. 1 Lac/SDP.
- Decrease by 0.1135907 MCM if the area irrigated by canal water were increased by 1000 hectares.
- Increase by 1.31742 MCM if subsidies were increased by Rs. 1 Crore.
- Increase by 1.035361 MCM if forest Cover were increased by 1 Square Kilometer.
- Increase by 14.41316 MCM if population density were increased by 1 per Square Kilometer.

5.6 Least Squares Dummy variable (LSDV) Model:

The predictions from the model in Table 2 can be improved by supplementing them with information that is contained in model residuals (i.e., differences between actual and predicted values). This can be done by introducing binary variables, which designate individual states. In a model with binary state indicator variables, the average value of residuals for each state is added to the predicted value for that state thus reducing the prediction error. Similarly, if the state residuals contain an increasing or decreasing time trend, such a state-specific trend can also be added to the prediction. However, the addition of separate intercepts and time trends for some states does increase the number of model parameters. If the resulting model is over-specified, the coefficients of the continuous variables, which form the structural component of the model, may be biased. Such bias is small when the inclusion of a state-specific intercept (or trend) does not result in an appreciable change in the value of the estimated coefficients of the structural variables.

Consider the model,

$$E_{it} = i\alpha_i + \sum_j \beta_j X^j_{it} + \varepsilon_{it} \qquad (3)$$

usually referred to as 'Least Squares Dummy variable' (LSDV) Model.

The Summary of the estimation is as follow;

Model	R	R Square	Adjusted R Square	Std. Error	Durbin-Watson
1	.997	.994	.991	1143.3071	2.052

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	7522456396.415	18	417914244.245	319.714	.000
	Residual	48364592.175	37	1307151.140		
	Total	7570820988.590	55			

Residuals Statistics

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	477.6821	54263.3086	16511.5198	11694.9534	56
Residual	-2065.0293	2455.6211	9.257E-13	937.7400	56
Std. Predicted Value	-1.371	3.228	.000	1.000	56
Std. Residual	-1.806	2.148	.000	.820	56

Coefficients

	Variables	Unstandardized Coefficients		Std Coeff	t	Sig.
Model		B	Std. Error	Beta		
1	CONSTANT	-34061.066	9295.889		-3.664	.001
	AGRI	4958.950	3847.493	.046	1.289	.205
	CANAL	-.114	.887	-.007	-.128	.899
	SUBSIDY	1.317	.302	.125	4.362	.000
	FOREST	1.035	.199	2.896	5.192	.000
	DENSITY	14.413	4.942	.254	2.916	.006
	Andhra Pradesh	-4288.573	1294.430	-.095	-3.313	.002
	Bihar	10770.608	4405.993	.239	2.445	.019
	Gujarat	28310.588	6591.894	.627	4.295	.000
	Haryana	33976.698	9219.341	.753	3.685	.001
	Karnataka	2052.048	2773.766	.045	.740	.464
	Kerala	14073.658	7615.105	.312	1.848	.073
	Madhya Pradesh	-91277.236	17493.665	-2.022	-5.218	.000
	Orissa	-14137.902	974.682	-.313	-14.505	.000
	Punjab	46561.944	9050.816	1.031	5.145	.000
	Rajasthan	25619.055	6554.869	.567	3.908	.000
	Tamil Nadu	30159.598	5919.898	.668	5.095	.000
	Uttar Pradesh	37312.801	4104.962	.826	9.090	.000
	West Bengal	21372.389	8220.829	.473	2.600	.013

Interpretation of LSDV model is not so important. It is customary to introduce $n - 1$ dummies for n characters. It is left to the researcher to choose the state to be dropped to avoid 'dummy variable trap'. Here in our 14 states model, Maharashtra has been dropped. State specific intercept terms change as one changes the state to be dropped. In relation to Maharashtra all the states intercept coefficients are statistically significant except for Karnataka. Andhra Pradesh, Madhya Pradesh and Orissa have shown negative extraction.

CHAPTER 6

CONCLUSION

An important ground water allocation issue is how to evaluate current versus future use of ground water. Unfortunately, states rarely consider future ground water uses in establishing ground water allocation policies dealing with ground water depletion. The states that do have explicit policies to limit ground water depletion typically simply prohibit additional ground water uses and do little to regulate current ground water uses to extend aquifer life. There is unfortunately too little attention given to regulating existing ground water uses to lengthen aquifer life, let alone any explicit quantitative evaluation of the trade-off between current and future ground water use. Consequently, ground water valuation has historically played almost no role in state ground water allocation policies. Ground water policies in most states could be strengthened by acknowledging ground water's future value.

To understand the problem better we have posed the ground water problem in sole ownership framework. We have tried to explain the nature of state variable, stock of water and control variable, harvesting. Using Hamiltonian, we have solved for the sole owner's objective function with respect to a dynamic constraint. We have discussed the motion of the function where we have proposed an optimal rate of harvesting given the stock of water. Further we have posed the problem under two regimes – controlled and uncontrolled, wherein we prove that uncontrolled regime is costlier than controlled regime and the benefit of the latter for sustainable harvesting of ground water resources. We have also proposed alternatives such as taxes and permits to control indiscriminate harvesting.

Realizing the fact that none owns ground water due to ill – defined property rights, too many extractors (heterogeneous users), controlling harvesting is practically not possible. In spite of the practical problem associated with direct observation over the ground water exploitation, it is not inconceivable to control exploitation by indirect measures. We, from a broad literature survey, have found a set of factors determining the ground water extraction such as SDP, population, urbanization, forest cover, subsidies and etc. Juxtaposing all these factors, we have formed five policy variables. We have set up a regression model which would explain the variation in extraction by a set of policy variables. In our experiment we have found out the determinants of ground water extraction and have proposed some of the indirect methods to control over exploitation of ground water. An empirical model has been used for this purpose. The model is tested using interstate analysis of the Indian Economy for the period of 1980 – 2000. Since the model constitutes pooled (Time Series & Cross Section) data across states over the years, Panel Regression Analysis has been performed. From this exercise we found that forest, subsidies and population density appearing as key factors in explaining the ground water extraction. On the basis of these findings we thus suggest in this paper certain indirect policy measures for sustainability of ground water.

Policy Suggestions:

From this exercise we found that forest, subsidies and population density appearing as key factors in explaining the ground water extraction. With respect to forest, its nothing other than protecting forests, afforestation are to be suggested. Two positive effects from forest variable are observed. First, increased forest increases the recharge capacity of the aquifers, resulting in an increased water table leading to higher extraction and Second, increased afforestation, plantation activity leading to higher extraction. Both have long run beneficiary effects, yet the former provides more water at lower cost of extraction. Stringent direct and indirect measures of population control programs should be implemented keeping well in mind that the per capita availability of water and alarming 'WATER STRESS'.

Proper crop management policy is required. Water intensive crop should be encouraged to cultivate in water abundant states and districts within states. Production planning should be on the basis of 'Comparative Advantage'. Least cost product is produced, specialized and exported yet earning interregional[1] trade gains. There is a need for re-structuring crop production policy. Policies encouraging dry farming (cotton, maize, etc) where water problem is acute are to be implemented.

Dealing with subsidies requires special attention, as it also invokes the global market in terms of AOA under WTO. Government's recent procurement price policy, indiscriminant subsidies and other likely mechanisms have resulted in higher extraction of ground water in states like Punjab, Haryana, Rajasthan, Andhra Pradesh and Gujarat where the water problem is acute.

Government should discriminate between states. Encourage those states with subsidies to grow water intensive crops where water is abundant and discourage where water is scarce. Encouraging dry farming in water scarce states via subsidies would do the most required job. Understanding the necessity of water, agricultural production, rural base, etc, in a developing country like India, we would argue that we are not against subsidies scheme. Prioritizing and supporting the production of state specific crops according to availability of water (comparative advantage), and yet resulting inter and intra-regional trade would help states gain and hence consequent achievement of self-sufficiency, and sustainable development of ground water resources. We emphasize the following points:

(a) There is a need for establishing an integrated National and State Ground water Data storage and Retrieval System to collect, store, update, process and disseminate ground water Data to enable planning and management of ground water resources.

(b) There is a need for constituting a vigilance committee to look after data storage which would take severe action against repeating the data year after year in 'Ground Water Statistics Publications'. This is also in concern with maintaining meaningless arbitrary numbers cited during data collection period.

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[1] Ohlin, Bertil, 'Interregional and International Trade' – 1933.

The problem of ground water is epitomized in India where annual precipitation is concentrated in the 4 months of the monsoon, and then in only a few hours of these months. Because of the sporadic spatial and temporal distribution of precipitation, the only way water supply can be controlled to match demand is through storage. This is true whether the demand is for natural processes or human needs. In natural systems, precipitation may be intercepted by vegetation and temporarily stored on plant surfaces and on the soil surface. When water infiltrates the ground, it is stored in the soil and may percolate to groundwater storage. On the land, surface water is stored in watercourses, lakes, and other water bodies and in frozen form as snow and ice. Man can create and enhance water storage by such activities as water conservation tillage, constructing dams and dikes to impound water, and artificially recharging groundwater. Regardless of the method or type of storage, the purpose is to capture water when and where its marginal value is low—or, as in the case of floods, even negative—and reallocate it to times and places where its marginal value is high. Here, "marginal value" includes all of the economic, social, and environmental values of water.

Effective economic and management policies are needed to prevent the crisis that threatens India in the coming years. Good management of the country's water resources will effectively reduce the amount of pollution and over exploitation that is currently plaguing. The consequent improvement in water quantity and quality will also have repercussions in terms of ameliorating human and environmental health. In the past few years, the govt. has recognized the importance of promoting the sustainable management of India's water resources and has placed water as one of its main priorities in the coming decades.

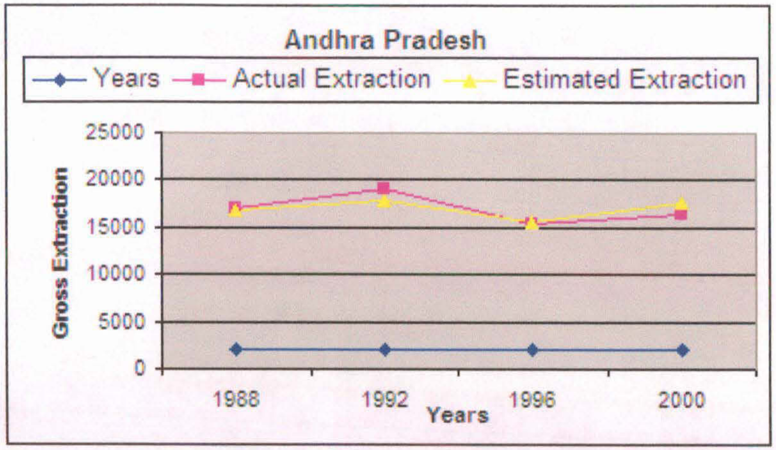
APPENDIX-1

TABLE 1 - GROUNDWATER EXTRACTION OF INDIAN STATES OVER THE YEARS				
GROSS DRAFT (M.C.M/Yr)				
	1987 -1990	**1992 - 1994**	**1995 - 1996**	**1998 -2000**
ANDHRA PRADESH	17090.71429	19047.95571	15425.53	16479.88571
ARUNACHAL PRADESH	216	215.77	215.78	215.8
ASSAM	4180.428571	4389.317143	5053.661429	5407.371429
BIHAR	14725.57143	12899	12838.86429	18562.31429
GOA	201	173.35	54.74	54.7
GUJARAT	12542.57143	13625.44714	13299.44143	15246.17143
HARYANA	8540.285714	9581.142857	9964.401429	11940.61429
HIMACHAL PRADESH	160.5714286	167.2971429	148.5885714	102.9
JAMMU & KASHMIR	754.7142857	759.9185714	735.3371429	721.5714286
KARNATAKA	9098	7706.371429	8572.165714	8915.885714
KERALA	2183.142857	2750.937143	2750.937143	3100.5
MADHYA PRADESH	17995.14286	19431.31429	17820.26143	19275.25714
MAHARASHTRA	16846.57143	17794.09571	23454.27143	25021.58571
MANIPUR	18	473	473	473
MEGHALAYA	64.34285714	185	106.95	107
MIZORAM	**NA**	**NA**	**NA**	**NA**
NAGALAND	8	109	109	109
ORISSA	4849.142857	5508.065714	5044.5	6738.871429
PUNJAB	24382.14286	24300.78429	24376.5	24822.05714
RAJASTHAN	9976.571429	10221.76429	9742.64	13032.7
SIKKIM	**NA**	**NA**	**NA**	**NA**
TAMIL NADU	21650.28571	23326.85714	23326.84714	24017.85714
TRIPURA	164	515.5714286	368.7957143	368.7857143
UTTAR PRADESH	47702.28571	50721.28571	50909.24429	56302.71429
WEST BENGAL	7264.571429	9169.414286	10242.96429	12488.7
NCT DELHI	486	356.8571429	346.9914286	362.4714286

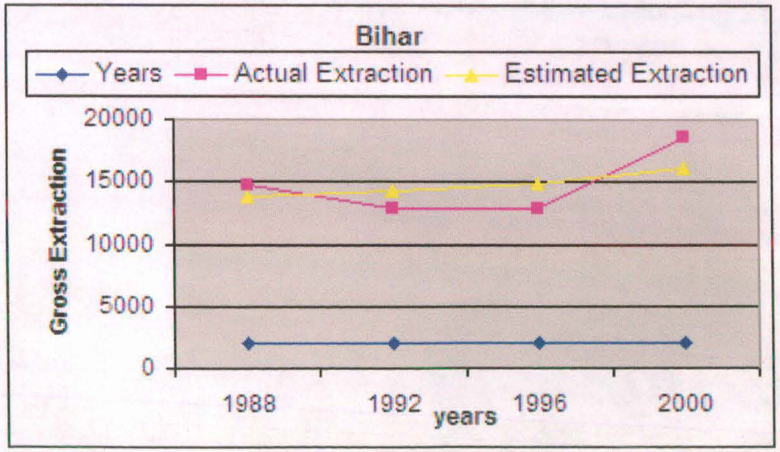
Source: Ground water Statistics, 1986 – 2000, Central Ground water Board, Ministry of Water Resources, Faridabad.

APPENDIX 2

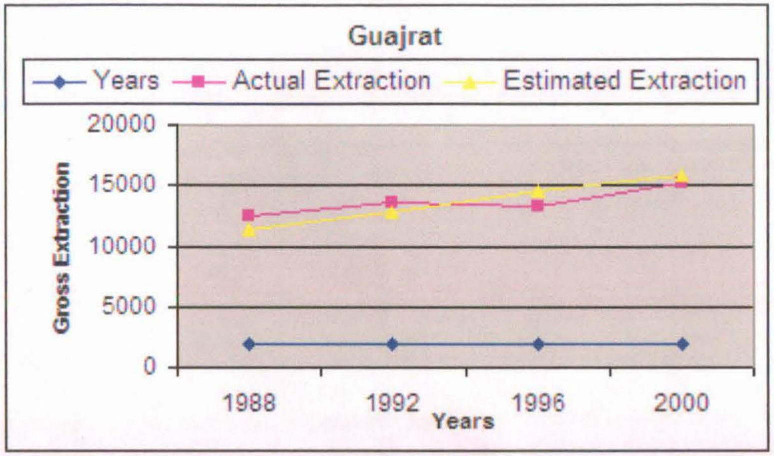
State	Years	Actual Extraction	Estimated Extraction
AP	1988	17090.7	16890.742
	1992	19048	17905.118
	1996	15425.5	15539.649
	2000	16479.9	17708.582



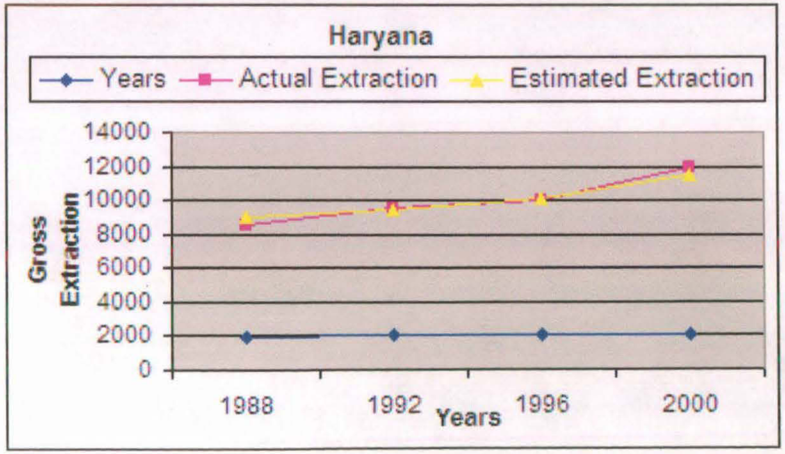
State	Years	Actual Extraction	Estimated Extraction
Bihar	1988	14725.6	13754.449
	1992	12899	14260.713
	1996	12838.9	14903.889
	2000	18562.3	16106.689



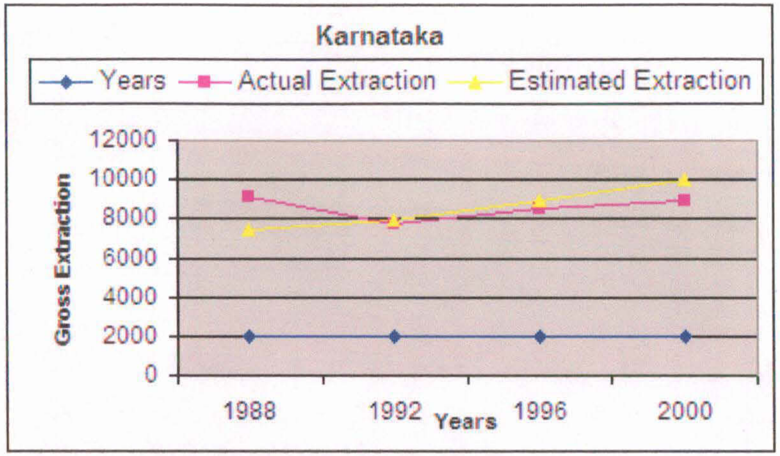
State	Years	Actual Extraction	Estimated Extraction
Gujarat	1988	12542.6	11389.287
	1992	13625.5	12862.652
	1996	13299.4	14606.607
	2000	15246.2	15855.085



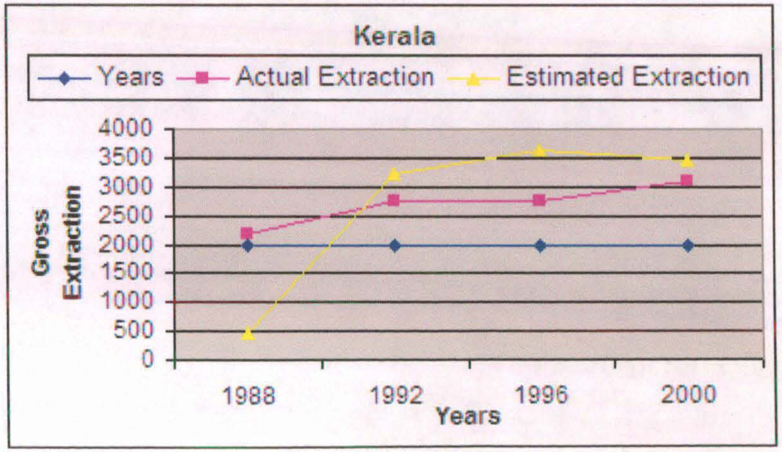
State	Years	Actual Extraction	Estimated Extraction
Haryana	1988	8540.29	8944.6092
	1992	9581.14	9424.7846
	1996	9964.4	10141.851
	2000	11940.6	11515.195



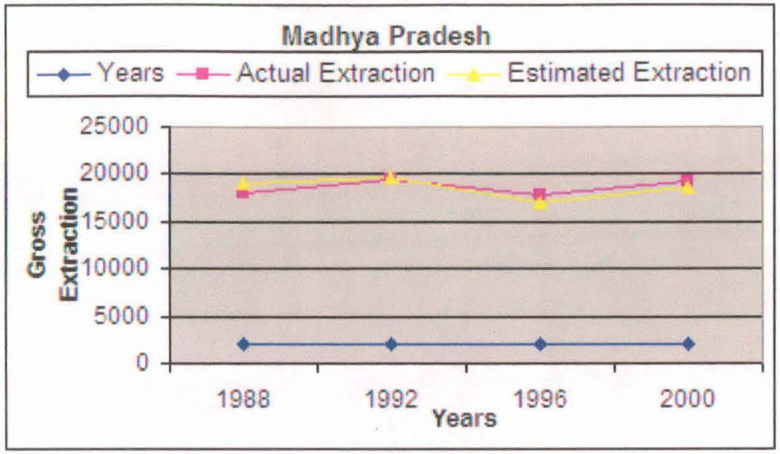
State	Years	Actual Extraction	Estimated Extraction
Karnataka	1988	9098	7416.1101
	1992	7706.37	7914.0403
	1996	8572.17	8956.2305
	2000	8915.89	10006.049



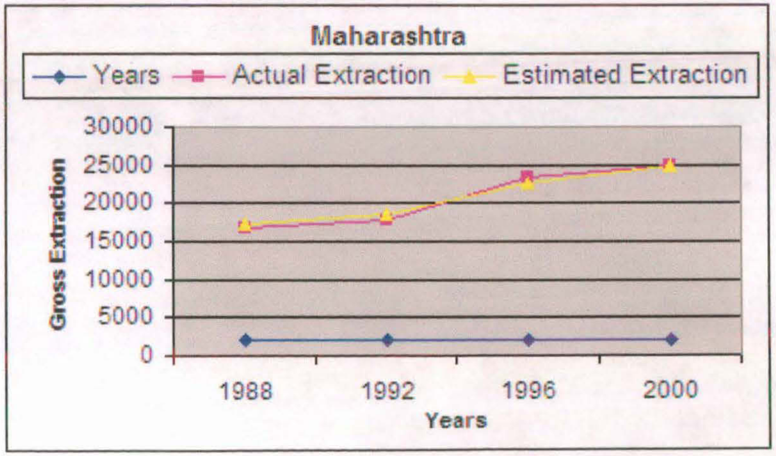
State	Years	Actual Extraction	Estimated Extraction
Kerala	1988	2183.14	477.6821
	1992	2750.94	3220.5595
	1996	2750.94	3631.3186
	2000	3100.5	3455.9598



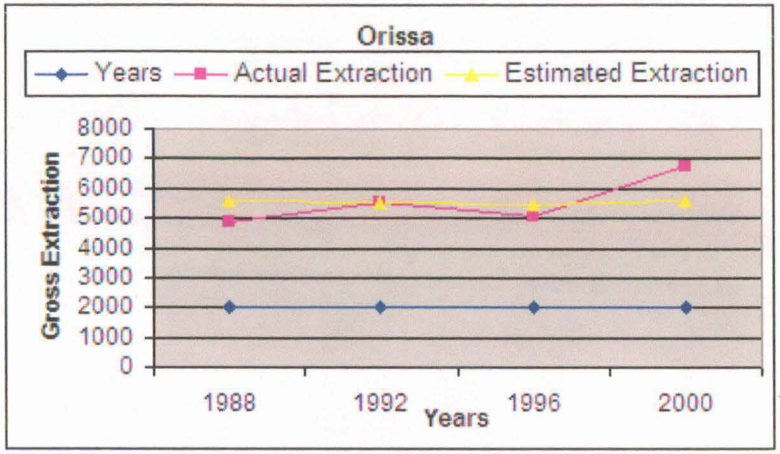
State	Years	Actual Extraction	Estimated Extraction
MP	1988	17995.1	19038.019
	1992	19431.3	19715.407
	1996	17820.3	17021.113
	2000	19275.3	18747.432



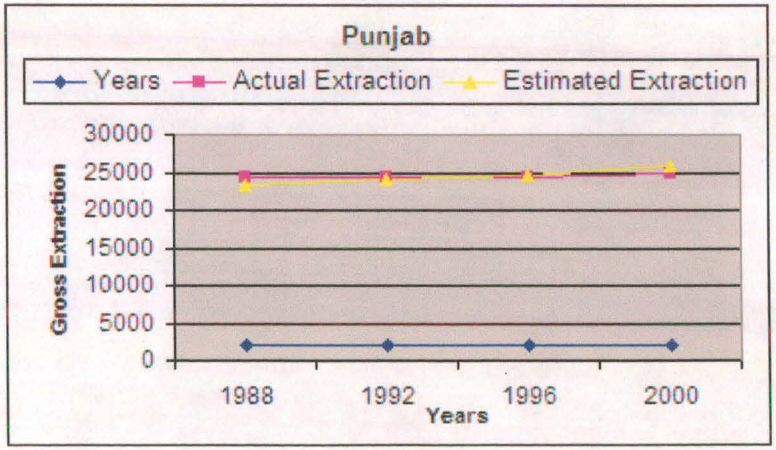
State	Years	Actual Extraction	Estimated Extraction
MH	1988	16846.6	17192.382
	1992	17794.1	18444.619
	1996	23454.3	22647.577
	2000	25021.6	24831.952



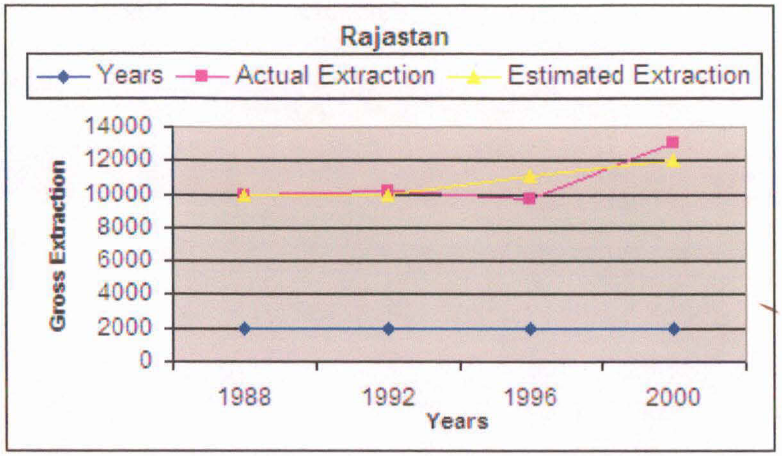
State	Years	Actual Extraction	Estimated Extraction
Orissa	1988	4849.14	5563.2039
	1992	5508.07	5540.6474
	1996	5044.5	5445.8521
	2000	6738.87	5590.8766



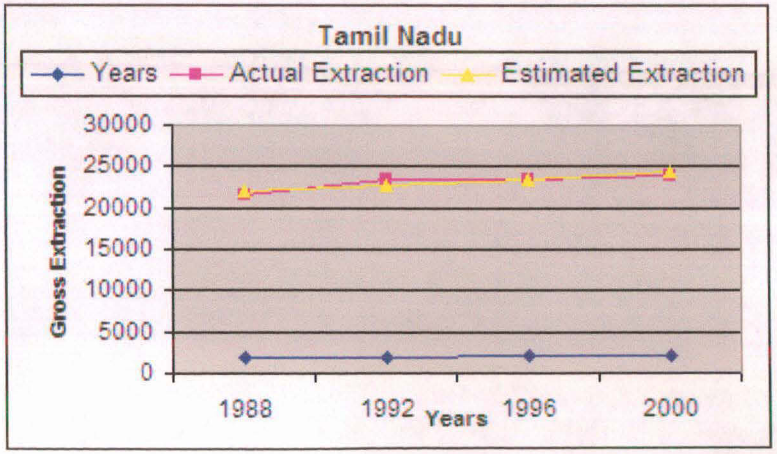
State	Years	Actual Extraction	Estimated Extraction
Punjab	1988	24382.1	23252.733
	1992	24300.8	24083.41
	1996	24376.5	24730.744
	2000	24822.1	25814.593



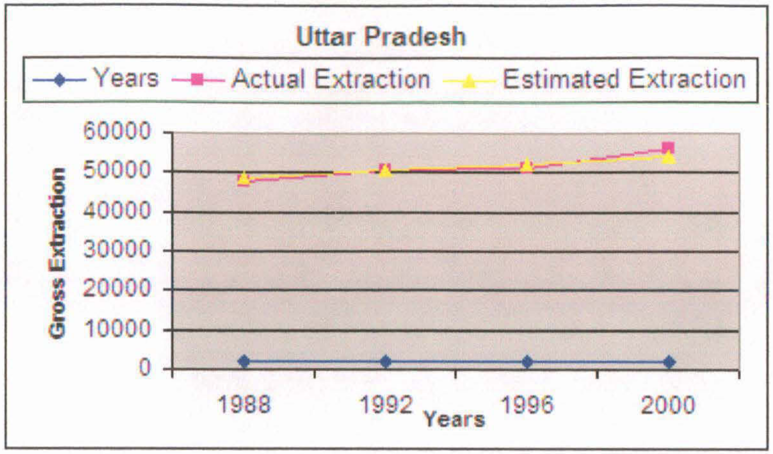
State	Years	Actual Extraction	Estimated Extraction
Rajastan	1988	9976.57	9929.1143
	1992	10221.8	9898.3792
	1996	9742.64	11099.51
	2000	13032.7	12046.667



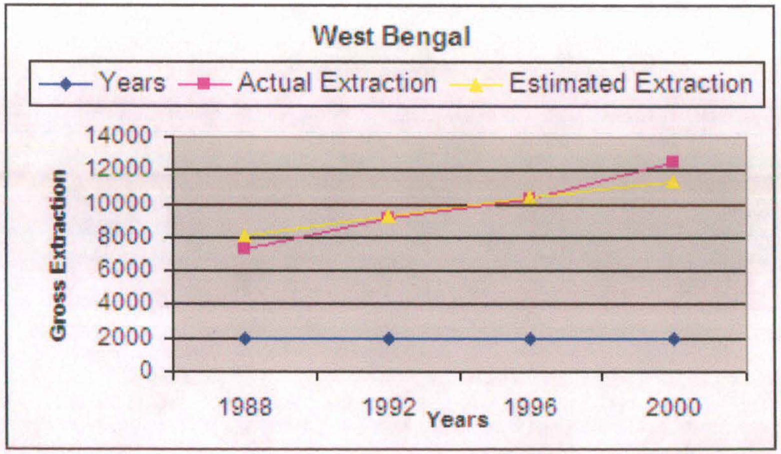
State	Years	Actual Extraction	Estimated Extraction
TN	1988	21650.3	21945.059
	1992	23326.9	22668.971
	1996	23326.9	23375.34
	2000	24017.9	24332.49



State	Years	Actual Extraction	Estimated Extraction
UP	1988	47702.3	48454.839
	1992	50721.3	50677.59
	1996	50909.2	52239.791
	2000	56302.7	54263.311



State	Years	Actual Extraction	Estimated Extraction
WB	1988	7264.57	8100.6441
	1992	9169.41	9290.8254
	1996	10243	10406.239
	2000	12488.7	11367.931



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