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Soil Science

Assessment of Rainwater Harvesting Capacity of Check Dam Reservoirs in Barkachha, a Part of Central Vindhyan Plateau of Mirzapur District, Uttar Pradesh, India

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Abstract

Barkachha, a part of central Vindhyan plateau is rocky and undulating land having many small rivulets and channels which quickly drain away the bounties of rainwater along with the fine crust of the top fertile soil. To overcome this situation, two check dam were constructed by the Uttar Pradesh Irrigation Department, during 2001. The present study was under taken to evaluate the rainwater harvesting capacity of these reservoirs for supplementary irrigation of the cultivated crops, *viz* cereal, pulses and oil seeds. The runoff water accumulated from July and remains up to February/March. Maximum volume of the harvested rainwater in both the reservoirs was during September with a capacity 22550 m^3 and 121170 m^3 in reservoir No. 1 and reservoir No. 2, respectively. There was no water during the month of April to June in both the reservoirs. The crop producing area under these reservoirs through supplementary irrigation for the last one decade varied from 17.5 to 26.1 ha.

Highlights

- Harvested rainwater volumes in check dams were observed highest in month of September in Vindhyan plateau, Mirzapur.
- Total cultivated areas under different crops were in average 20.94 ha for the supplementary irrigation from harvested rainwater.

Keywords: Rainwater harvesting, Check dam reservoir, rainfall index, Vindhyan plateau, Mirzapur

Introduction

Rainfall is the principal source of water, which augments soil moisture, ground water and surface flow. Agriculture and several other economic activities in sub-tropical to dry areas (Shinde *et al*., 2012) depend on rainfall. Rainfall in dry areas is of convective nature and usually occurs at a very high intensity for shorter duration generating high runoff in response of even little rainfall. The runoff depends

upon rainfall intensity and catchment characteristics particularly area, surface roughness, water absorbing capacity of the soil and slope etc. Harvesting and recycling of rainwater in dry lands is important in order to improve water use efficiency.

In addition, in order to reduce costs, farmers may decide to cease or reduce irrigation of some normally irrigated crops. Recent research has shown that some practical techniques of rainwater harvesting (Li *et al.,* 2007) and supplementary irrigation, can be used to improve crop yields and production stability of farmland ecosystem (Zhao *et al.,* 2005; Xiao *et al.,* 2007). The storage is made in/on the ground, surface or underground depending upon the topography of the land (Tripathi and Pandey, 2005), type of surface and sub-surface soils and the geological formation. Storage cisterns, check dam, farm ponds, percolation tank, irrigation tanks and reservoir comprise the surface storage system. Rainwater harvesting into check dam type reservoir for supplemental irrigation during intra-seasonal dry spells for the crop growing seasons of plateau regions could therefore prove to be a possible solution. Rainwater harvesting may also be used for (Malesu *et al*., 2008) restoration of the productivity of land which suffers from insufficient rainfall, increasing productivity of rainfed farming (Oweis and Hachum, 2006), minimizing risk of drought in areas prone to it and decrease the threat of desertification through decreasing runoff and increasing infiltration.

Rajiv Gandhi South Campus of Banaras Hindu University, Barkachha is situated about 8 km South West of Mirzapur town, a part of central Vindhyan plateau. The area being rocky and undulating, the underground water resources are uncertain, unpredictable and inadequate to meet the requirements of agriculture. Due to undulating topography, many small rivulets and channels intersecting the area quickly drain away the bounties of rainfall along with the fine crust of the top fertile soil. To overcome these situation, two check dam (*bundhi*) reservoirs were constructed by the Uttar Pradesh, Irrigation Department (Irrigation Work Circle, Mirzapur), in Barkachha, Mirzapur, South Campus of Banaras Hindu University for rainwater harvesting, during 2001. Keeping the above mentioned importance of these check dam reservoirs in central Vindhyan plateau region of Barkachha, Mirzapur district, this study was undertaken to evaluate the pattern of rainfall in this region and to assess the runoff rainwater harvesting capacity of check dam reservoirs, constructed by irrigation department.

Materials and Methods

Study area

The present study was carried out in Barkachha farm (Fig. 1) popularly known as Rajiv Gandhi South Campus of Banaras Hindu University. The Barkachha farm is located in central Vindhyan plateau region of the district Mirzapur and lies between 25^0002 to 25^0152 North latitude and 82^0 452 East longitude. The farm is situated at an altitude of 180.59 m above mean sea level. The topography of the farm is undulating and surface is rough. The Barkachha farm has an area of 1010 ha and is situated from 8 km South-West of Mirzapur - Rabertganj highway. The river Khjuri flow on the eastern border of the farm, many streamlets flow across the area resulting in excessive runoff during rainy season. According to ICAR survey report (Soil Survey Report No. 423, ICAR, March 1971), nearly 40 % land of this farm is rocky, i.e. surface with bed rock exposure (1-25 % slope). Approximately 60 % farm land is having low to moderate deep soil, 1-5 % slope and slight to moderate surface erosion. The red soil, generally red to reddish brown, lighter texture with friable structure is commonly observed at the farm. But, slightly alkaline, calcarious soil is also found in some (6.68 %) patches. This farm has both types of land, i.e. cultivable and non cultivable. Variety of crops such as cereals, pulses, oilseed crops, horticultural crops (fruits and vegetables), bio-fuel crop as well as medicinal and aromatic plants are grown in cultivable land of Barkachha. Overall climate of the area is semi-arid and sub-humid.

Check dam reservoirs

Two rainwater harvesting check dam reservoirs were constructed by the Irrigation Department, Government of Uttar Pradesh in collaboration with Krishi Vigyan Kendra, Barkachha (ICAR) during 2001. The check dam reservoir No. 1 was constructed on the back side of University guest house and the check dam reservoir No. 2 was constructed on the back side of the girl's hostel in Barkachha farm. The length, top width of check dam, maximum height, side slopes and catchment areas of check dam reservoirs were described in Table 1.

Depth of the check dam reservoirs at different slopes were measured randomly by setting the graduated wooden poles and conformed by measuring tape. The isolines were drawn accordingly to the different depth of the reservoirs along with elevated top width of the respective reservoirs. Finally the contour maps of the two reservoirs were drawn by chorochromatic method.

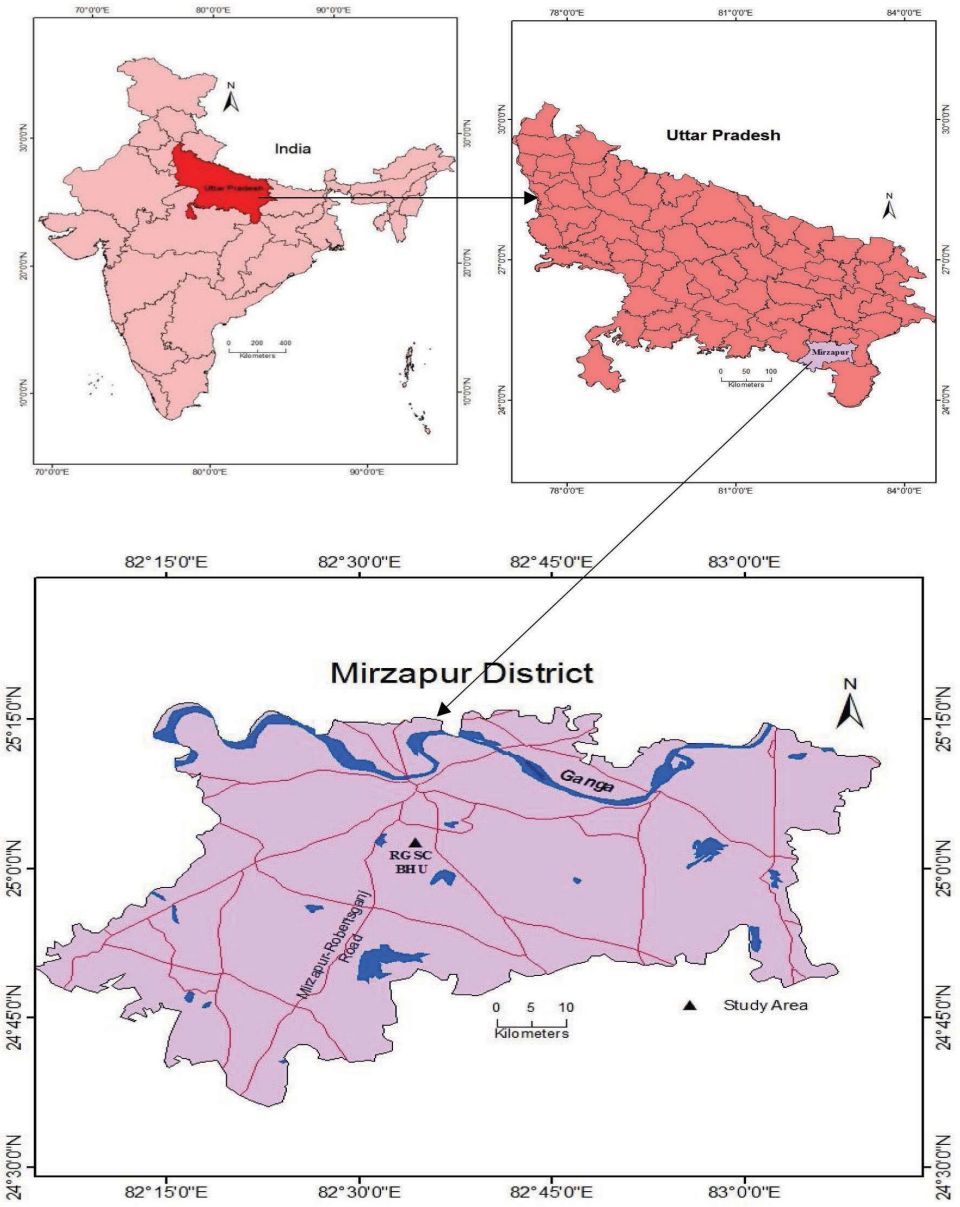

Fig. 1: Location map of study area

Table 1: Construction design of Check dam reservoirs in Barkachha, Mirzapur

S.No.	Design parameter	Reservoir No.1	Reservoir No.2
i	Length (m)	400.0	400.0
ii	Top width (m) of check dam	6.0	6.0
ii	Maximum height/depth (m)	5.0	6.0
iv	Side slope	2:1(up to 3 m)2.5:1(>3m<5m)	2:1(up to 3 m)2.5:1(>3m<5m)
v	Catchment area (km^2)	2.59	2.59

The depth (h) of the water table of the harvested rainwater at different locations of the reservoirs was measured by graduated wooden poles. The monthly average volume of harvested rainwater was calculated by applying the formula of cylinder.

Data collection and analysis

Annual average meteorological data from 2000 to 2009 and monthly average meteorological data of the study year (2009) was collected from the Indian Meteorological Department, Pune and Meteorological Division, *Krishi Vigyan Kendra*, Mirzapur, respectively. The statistical correlation (Pearson) was calculated among the meteorological data with the average volume of rainwater harvested in check dam reservoirs. Year wise data on crop production area (2000-2009) of the cultivable lands, which are under supplementary irrigation through these check dam reservoirs, were collected from the farm superintendent, Barkachha farm.

Results and Discussion

Rainfall distribution and associated climatic features

The average annual rainfall and its associated climatic data for the period of one decade (2000 to 2009) of Barkachha, Mirzapur are presented in Table 2. The rainfall and associated meteorological data for a particular area is needed for harvesting and utilizing the runoff water. Marked variations were observed in yearly rainfall over the ten years (2000-2009) period. During this time period, highest annual rainfall (1615.4 mm) was received during the year 2008 and lowest annual rainfall (577.9 mm) was received during the year 2002. The average annual rainfall in Barkachha over the period 2000-2009 was 968.5 mm. Most of the rainfall events in this area have a short duration but high intensity. In order to classify the annual rainfall amounts, the rainfall index (Schiettecatte *et al.*, 2005) has been used. Accordingly most of years (2000-2009) were classified as dry (60 %) or extremely dry (10 %) period (Table 3). Considering the annual average data on temperature, humidity, sunshine and evaporation of Mirzapur (Table 2), the climate in the region of Barkachha farm is warm and semi arid to sub humid. The annual average evapotranspiration (ET) of the area was 1525 mm in Mirzapur. The balance between the total rainfall and evapotranspiration is generally excessive during rainy season (July to October). However, in subsequent months from November onwards to June, it is deficient. The magnitude is always higher during summer than in autumn and winter months.

Rainfall received as well as the associated climate data (2009) during the period of study is presented in Table 4. The period of onset of monsoon in this region was last week of May. More than 95 % of the annual rainfall was received during monsoon season, but it was erratic and unpredictable. Out of 365 days, only 31 days were rainy day in 2009. Maximum rainfall (354.2 mm) was received during the month of July. There was a light shower during the month of May and June. The period of November to April did not receive rain. This trend of monsoon rains coupled with high temperature and the existing toposequence of the central Vindhyan plateau of Barkachha, Mirzapur district leads to imbalance between rain received and vegetation water demand.

Table 2: Average annual meteorological data of Mirzapur, Uttar Pradesh

Years	Annual rainfall (mm)	Temperature (°C)		Relative humidity (%)		Average wind velocity (km/hr)	Sunshine (hr)	Average Evaporation (mm/day)
		Max.	Min.	Max.	Min.			
2000	863.9	31.37	19.33	81	52	4.31	7.14	4.28
2001	1123.2	31.37	19.40	78	53	3.98	6.89	3.84
2002	577.9	31.75	19.66	81	48	4.63	6.79	4.18
2003	1448.0	30.97	19.78	81	51	4.58	6.89	3.75
2004	846.4	31.25	19.21	80	50	2.84	7.61	3.67
2005	847.2	32.14	19.80	78	49	1.98	7.25	3.66
2006	848.0	31.81	18.47	78	47	2.51	7.54	4.23
2007	742.6	31.74	19.29	74	47	3.95	7.22	3.92
2008	1615.4	31.73	20.17	74	48	4.20	6.67	4.09
2009	773.9	33.05	19.99	72	43	4.27	7.43	3.86

Table 3: Classification of annual rainfall data recorded in Barkachha (period 2000-2009) according to the rainfall index

Index value x^a	Interpretation	Percentage of years (%)
x<-0.4	Extremely dry	10
-0.4<x<-0.1	Dry	60
-0.1<x<0.1	Normal	-
0.1<x<0.4	Wet	10
0.4<x	Very wet	20

x^a = (annual precipitation-average annual precipitation)/average annual precipitation

Table 4: Monthly meteorological data (2009) of Mirzapur, Uttar Pradesh

Month	Monthly rainfall (mm)	Rainy day	Temperature (°C)		Relative humidity (%)		Average wind velocity (km/hr)	Sunshine (hr)	Average Evaporation (mm/day)
			Max.	Min.	Max.	Min.			
January	0.0	0	23.6	11.1	87	49	3.0	5.9	1.7
February	0.0	0	28.0	12.4	76	33	5.3	9.2	3.2
March	0.0	0	33.7	16.8	53	25	3.6	8.7	4.5
April	0.0	0	39.3	22.4	37	13	5.2	9.9	8.7
May	29.8	1	38.5	26.4	63	36	7.5	9.3	8.0
June	25.6	2	41.1	28.2	56	32	5.0	7.3	8.5
July	354.2	14	34.1	27.3	80	63	6.1	5.4	5.0
August	123.5	7	32.9	26.9	83	69	4.9	4.8	4.1
September	168.0	4	33.2	25.7	83	66	3.8	6.8	3.5
October	72.8	3	31.2	19.7	78	46	2.6	8.1	3.1
November	0.0	0	28.6	15.2	82	42	2.4	6.5	2.1
December	0.0	0	24.5	11.0	86	39	1.7	6.4	1.5

Rainwater harvesting check dam reservoir

The check dams were constructed by scrapping the soil from upstream. The stone pitching was done on downstream face of the check dams by using locally available stone spalls and boulder. According to contour maps (Fig. 2) of the two reservoirs, the reservoir No. 1 is wide V-shaped, where as the shape of the reservoir No. 2 is trumbler.

Total volume of rainwater harvested (Table 5) was calculated on the basis of average depth of water level

Table 5: Seasonal average (Av.) water depth (2009-10) and volume of water in check dam reservoirs in Barkachha, Mirzapur

Month	Reservoir No.1		Reservoir No.2	
	Av. depth of water (m)	Volume of water ('000 m^3)	Av. depth of water (m)	Volume of water ('000 m^3)
April, 2009	-	-	-	-
May, 2009	-	-	-	-
June, 2009	-	-	-	-
July, 2009	0.81	14.39	1.35	44.79
August, 2009	0.65	9.05	1.50	63.90
September, 2009	1.11	22.55	2.25	121.17
October, 2009	1.00	18.98	1.98	97.77
November, 2009	0.80	14.12	1.27	27.09
December, 2009	0.61	8.24	1.00	11.52
January, 2010	0.52	6.45	0.93	6.13
February, 2010	0.29	1.46	0.85	1.73
March, 2010	-	-	0.54	0.32

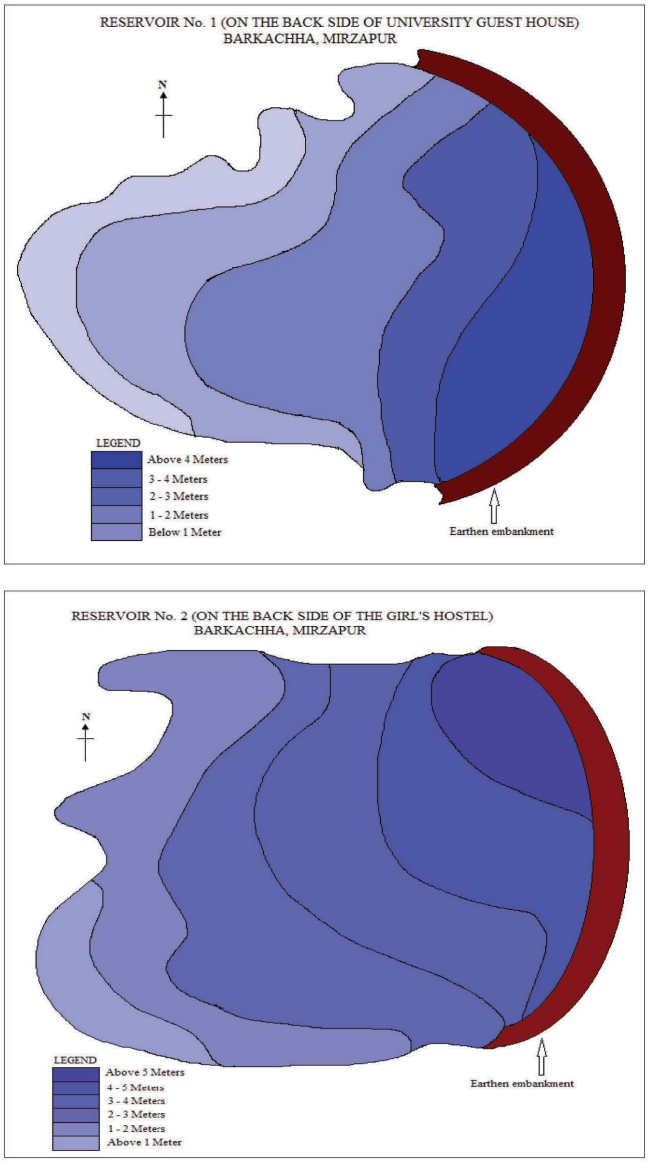

Fig. 2: Contour maps of check dam reservoirs in Barkachha, Rajiv Gandhi South Campus, Banaras Hindu University.

obtained in the respective check dam reservoirs. The depth of water level in reservoirs was measured at weekly interval from the onset of monsoon on ward at different points along the contour of the respective reservoirs the average was considered for contour mapping. Maximum volume of the harvested runoff rainwater in both the check dam reservoirs was in the month of September were 22550 m^3 and 121170 m^3 in reservoir No. 1 and No. 2, respectively. Thus, the volume of harvested water in reservoir No. 2 was approximately more than 5 times higher than in reservoir No.1. The runoff was received from the month of July. The stored water was retained up to February in the reservoir No. 1 and up to March in the reservoir No. 2. There was no stored water from the month of April to June in both the reservoirs.

Correlation of the meteorological data with the volume of harvested water in the two reservoirs is presented in Table 6. The volume of harvested rainwater in both the reservoirs was positively and significantly correlated with average total rainfall and relative humidity (RH) of the region. Thus, to preserve the harvested rainwater in the reservoirs, micro-climate can be altered by improving the humidity of the region, i.e. through perennial heat tolerance tree plantation in the adjoining side of the check dam of the reservoirs.

Supplementary irrigation for crop production

Water harvested in the check dam reservoirs was mostly utilized judiciously for supplementary irrigation and domestic (hostel) purpose in Barkachha. The area of crops which was provided supplementary irrigation through the harvested water of check dam reservoirs for last one decade (2000-2009) is presented in Table 7 and 8. Irrigation in Barkachha farm is basically concerned as life saving irrigation to the crops under various agricultural systems, as it is dryland area of Mirzapur district. The cereals (rice,

Table 6: Correlation of harvested water volume in reservoir with meteorological data.

Pearson correlation (2 tailed)	Meteorological Data								
	Rainfall	Rainy day	Temperature		Relative Humidity		Wind Velocity	Sunshine	Evaporation
			Max.	Mini.	Max.	Mini.			
Volume of water (Reservoir No. 1)	0.576* (0.05)	0.473 (0.12)	-0.193 (0.54)	0.191 (0.55)	0.570* (0.05)	0.685** (0.01)	-0.363 (0.24)	-0.455 (0.13)	-0.440 (0.15)
Volume of water (Reservoir No. 2)	0.546* (0.06)	0.453 (0.13)	-0.064 (0.84)	0.330 (0.29)	0.574* (0.12)	0.721** (0.00)	-0.228 (0.47)	-0.371 (0.23)	-0.314 (0.32)

*Correlation is significant at the 0.05 level
**Correlation is significant at the 0.01 level

wheat, maize and pearl millet), pulses (green gram, gram and lentil) and oil seeds (mustard and sesamum) are under this irrigation programme in this farm. The range of total area under the supplementary irrigation through check dam reservoir No. 1 and 2 were 19.4 to 26.1 ha and 17.5 to 24.0 ha, respectively for the last one decade. The share of irrigated area under the reservoir No. 1 was 62.63 % in cereal, 31.57 % in pulses and 5.80 % in oil seed crops; whereas under the reservoir No. 2, 63.66 % in cereal, 31.84 % in pulses and 4.50 % in oil seed crops, respectively in the year 2009. The productivity was increased by utilizing harvested rainwater.

Conclusion

The study demonstrated the usefulness of land management by water harvesting techniques through check dam reservoirs in reducing the amount of runoff and sedimentation and in enhancing soil moisture in semi arid/ sub humid regions of Barkachha, Mirzapur district. Water harvesting techniques through check dams have been utilized as a means to reduce soil erosion and to increase rainwater storage and soil fertility. Rainwater harvesting are also used for restoration of the productivity of land of rainfed farming, minimizing risk of drought in areas prone to it and decreasing the threat of desertification through decreasing runoff and increasing infiltration.

Table 7 Year wise crop production area (ha) under supplementary irrigation from reservoir No.1

Year	Cereal			Pulse			Oil seed			Total area
	Rice	Wheat	Maize	Pearl millet	Green gram	Gram	Lentil	Mustard	Sesamum	
2000	1.40	2.50	1.50	4.50	3.50	3.50	0.56	1.00	1.00	19.46
2001	2.05	2.60	1.50	3.60	3.90	5.80	1.60	1.80	1.50	24.35
2002	1.50	2.00	1.50	5.50	2.50	4.20	0.70	0.60	2.00	20.50
2003	2.50	3.50	2.00	5.20	3.50	4.30	1.80	1.70	1.60	26.10
2004	1.52	3.50	2.50	6.00	3.00	3.20	0.29	0.80	2.00	22.81
2005	1.50	2.50	2.50	5.50	3.5	3.00	0.24	0.50	1.00	20.24
2006	1.50	2.50	1.00	5.50	2.50	4.10	0.37	0.90	1.00	19.37
2007	1.36	3.00	1.50	6.00	2.00	3.90	0.36	0.50	1.50	20.12
2008	2.90	2.00	2.00	5.60	3.45	4.00	1.50	0.90	2.00	24.35
2009	1.50	1.90	2.50	6.30	2.25	3.60	0.30	0.63	0.50	19.48

Table 8: Year wise crop production area (ha) under supplementary irrigation from reservoir No.2

Year	Cereal			Pulse			Oil seed			Total area
	Rice	Wheat	Maize	Pearl millet	Green gram	Gram	Lentil	Mustard	Sesamum	
2000	1.50	2.20	1.50	4.50	3.40	3.40	0.20	0.40	0.40	17.50
2001	2.15	3.60	1.50	4.60	3.00	4.00	1.50	1.50	1.10	22.95
2002	1.52	2.10	1.18	5.00	2.50	4.40	0.60	0.50	0.50	18.30
2003	2.60	3.70	2.60	4.00	2.30	4.50	1.60	1.60	1.10	24.00
2004	1.60	2.50	2.00	5.00	3.50	3.50	0.25	0.50	0.50	19.35
2005	1.50	2.50	2.00	5.50	3.50	3.50	0.25	0.60	0.40	19.75
2006	1.55	2.50	1.60	5.50	2.40	4.00	0.38	0.60	0.35	18.88
2007	1.35	2.00	1.50	6.80	2.20	4.00	0.35	0.55	0.35	19.10
2008	3.00	3.00	2.50	4.50	4.50	3.50	1.35	0.60	0.30	23.25
2009	1.50	2.00	2.00	6.50	2.25	3.50	0.25	0.50	0.35	18.85

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