

US EPA ARCHIVE DOCUMENT

Appendix: Raw data, units, calculations and references for the annual energy and material flows in Table 1. Subsystems are given by Roman numerals from I to VI progressing toward the sea.

Notes	Item	Raw Data	Units (per year unless noted)	References and Assumptions
I. Farm land¹				
	Area	2.87E+08	m ²	Li et al. 2003
	Mean annual temperature	287	°K	http://forages.oregonstate.edu/organizations/seed/osc/tech-pubs/goat_ch
	Temperature of growing season	296	°K	Li et al. 2003
1	Mean annual solar radiation	1.19E+06	kcal/m ²	Zhang,1998
	Albedo	0.3		Zuo et al. 2004
	Formula for energy from the sun	area × average solar radiation×(1-Albedo) ×4186 J/kcal		
	Energy	1.00E+18	J	
2	Wind velocity	5	m/s	Zhu et al. 2004
	Geostrophic wind	8.34	m/s	Reiter 1969
	Air density	1.23	kg/m ³	
	Drag coefficient on land	2.00E-03		Garratt 1977
	Seconds in a year	3.15E+07	s	
	Energy formula	area × density × drag coefficient × (geostrophic wind velocity) ³ ×sec/y		
	Energy	1.29E+16	J	
3	Earth heat flux	75	mW/m2	http://www.heatflow.und.edu
	Energy formula	heat flux × area × seconds/y		
	Energy	6.79E+14	J	
4	Rainfall	1.025	m	
	Mean elevation	2	m	
	Density	1.00E+03	kg/m ³	
	Gravity	9.8	m/s ²	
	Geopotential energy of rain	area × mean elevation × rainfall × density × gravity		
	Energy	5.77E+12	J	
5	Gibbs free energy of rain formula	(8.314J/mole/deg)(287K)/(18g/mole)*ln(999990ppm/965000ppm)		
	Gibbs free energy per gram	4.72	J/g	At mean annual temperature
	Chemical potential energy of rain	area × rainfall × density × Gibbs free energy		
	Energy	1.39E+15	J	
6	River water inflow	4.70E+09	m ³	
	Density	1.00E+06	g/m ³	
	Mineral content	7.50E+02	ppm	Yancheng Reserve Committee,2000
	Gibbs free energy of river water	(8.314J/mole/deg)(287K)/(18g/mole)*ln((1E6-750)ppm/965000ppm)		
	Gibbs free energy at 287°K	4.62	J/g	Avg. annual temperature

	Energy formula	volume flow × density × Gibbs free energy	
	Energy	2.17E+16	J
7	River water for irrigation	0.61	m ³ /m ² Bai 2006
	Gibbs free energy river water	(8.314J/mole/deg)(296K)/(18g/mole)*ln((1e6-750)ppm/965000ppm)	
	Gibbs free energy at 296°K	4.77	J/g Avg. temp. growing season
	Energy	8.35E+14	J For 1.75E+08 m ³
			Bai 2006 converted to 9.26 base
8	Purchased input	1.45E+16	sej/ha Lan and Odum 1994, for Tr. Chinese labor and service.
	Total purchased emergy	Area* purchased emergy density	
	Emergy purchased	4.16E+20	sej
9	Productivity of rice	4457	kg/ha Bai 2006
	Rice harvested	1.28E+08	kg
	Energy value	14230	J/g Bai 2006
	Energy of rice harvest	1.82E+15	J
10	Rice left after harvest	50000	kg Dong et al. 2005
	Energy left	7.12E+11	J
11	River water outflow	Available energy in river water minus irrigation use	
	Energy	2.09E+16	J 4.52E+09 m ³

II. Aquaculture ponds

	Area	2.51E+08	m ²
1	Mean annual solar radiation	1.19E+06	kcal/m ² Zuo et al. 2004
	Albedo	0.3	Zuo et al. 2004
	Energy formula	area×average solar radiation×(1-Albedo)×4186J/kcal	
	Energy	8.75E+17	J
2	Wind velocity (metric)	5	m/s Zhu et al. 2004
	Geostrophic wind	8.34	m/s Reiter 1969
	Air density	1.23	kg/m ³
	Drag coefficient over water	1.00E-03	Garratt 1977
	Seconds in a year	3.15E+07	s
	Energy formula	area×density×drag coefficient × (geostrophic wind velocity) ³ ×sec/y	
	Energy	5.64E+15	J
3	Earth heat flux	75	mW/m2 http://www.heatflow.und.edu
	Energy formula	heat flux × area × seconds/y	
	Energy	5.94E+14	J
4	Rainfall	1.025	m
	Mean elevation	2	m
	Density	1.00E+03	kg/m ³
	Gravity	9.8	m/s ²
	Geopotential of rain	area × mean elevation × rainfall × density × gravity	

	Energy	5.04E+12	
5	Gibbs free energy of rain	4.73 J/g	At avg. annual temperature
	Chemical potential of rain	area × rainfall × density × Gibbs free energy	
	Energy	1.21E+15 J	
6	River water inflow	2.09E+16 J	From I.10 above
7	River water for aquaculture	4.5 m ³ /m ²	Liu and Luan 2000
	Energy	5.39E+15 J	1.13E+09 m ³
8	Mean NPP of Phytoplankton	5320 g/m ²	Zuo et al. 2004
	Standard energy value	5 kcal/g	Parsons and Takahashi, 1973
	Energy formula	area × average NPP of Phytoplankton × standard energy	
	Energy	2.79E+16 J	
9	N fertilizer	30 kg/ha	Liu and Luan 2000
	Total quantity	7.53E+05 kg	
10	P fertilizer	45 kg/ha	Liu and Luan 2000
	Total quantity	1.13E+06 kg	
11	Forage	7000 kg/ha	Liu and Luan 2000
	Total quantity	1.76E+08 kg	
12	Fry	636 kg/ha	Liu and Luan 2000
	Total quantity	1.60E+07 kg	
13	Electricity and other purchased input	2.73E+15 sej/ha	Lu et al. 2002a
	Total quantity	6.85E+19 sej	
14	Aquaculture productivity	2500 kg wwt. /ha	Liu and Luan 2000
	Energy value for cultured fish	4813 J/g	http://www.seagrant.wisc.edu/greatlakesfish/ctable/html
	Aquaculture output	area × productivity × standard energy	
		3.02E+14 J	
15	Benthic fauna left in pond	194 g wwt. /m ²	Dong et al. 2005
	Standard energy value	3767 J/g wwt.	USDA Nutrient Data Laboratory “Food Composition and Nutrition.” http://www.nal.usda.gov/fnic/cgi-bin/nut_search.pl
	Aquaculture output	area × productivity × dry ratio × standard energy	
		1.83E+14 J	
16	Annual increase of organic matter (OM) in mud	170 g dwt. /m ²	Liu and Luan 2000
	Standard energy value	5.00E+00 kcal/g	Gorham and Sanger (1967)
	Energy	8.93E+14 J	
17	River water outflow	available river water-irrigation	
	Energy	1.55E+16 J	3.40E+09 m ³

III. *Phragmites* and *Aeluropus*

	Area ²	2.47E+08	m ²	
	Area of <i>Phragmites</i>	1.07E+08	m ²	Li, 2000
	Area of <i>Aeluropus</i> and <i>Imperata</i>	1.40E+08	m ²	Li, 2000
1	Mean annual solar radiation	1.19E+06	kcal/m ² /y	Zhang, 1998
	Albedo	0.3		Zuo et al. 2004
	Energy	area × average of solar radiation × (1-Albedo) × 4186 J/kcal		
	Energy	8.61E+17	J	
2	Wind velocity (metric)	5	m/s	Zhu et al. 2004
	Geostrophic wind	8.34	m/s	Reiter 1969
	Air density	1.23	kg/m ³	
	Drag coefficient	2.00E-03		Garratt 1977
	Sec/year	3.15E+07	J	
	Energy formula	area × density × drag coefficient × (geostrophic wind velocity) ³ × sec/yer		
	Energy	1.11E+16		
3	Earth heat flux	75	mW/m ²	http://www.heatflow.und.edu
	Energy formula	heat flux × area × seconds/y		
	Energy	5.84E+14	J	
4	Rainfall	1.025	m	
	Mean elevation	2	m	
	Density	1.00E+03	kg/m ³	
	Gravity	9.8	m/s ²	
	Geopotential of rain	area × mean elevation × rainfall × density × gravity		
	Energy	4.96E+12	J	2.41E+8 m ³
5	Gibbs free energy of rain	4.72	J/g	At mean annual temperature
	Chemical potential of rain	area × rainfall × density × Gibbs free energy		
	Energy	1.20E+15	J	
6	River water inflow	1.55E+16	J	From II. 17 above
7	Evapotranspiration of <i>Phragmites</i>	NPP = 2.72E3	g/m ²	Li et al. 2004
	Water evapotranspired	700 × NPP or 1.90E+06	g/m ²	Li et al. 2004
	Gibbs free energy of rain and river	(8.314J/mole/deg)(296K)/(18g/mole) × ln((1E+6-698)/965000ppm)		
	Gibbs free energy at 296°K	4.78	J/g	Temp. growing season
	Energy of evapotranspiration	Area × evapotranspiration per area × Gibbs free energy		
	Evapotranspiration of <i>Phragmites</i>	1.07E+8 m ² × 700 × 2.72E+3 g/m ² /y × 4.78 J/g		
	Energy	9.74E+14	J	2.04E+08 m ³
	Evapotranspiration of <i>Aeluropus</i> and <i>Imperata</i>	(1-22%) × Pan Evaporation = 78% × 1.5355m		
	Energy of evapotranspiration	area × evapotranspiration per area × density × Gibbs free energy		

Calculation	$1.40\text{E}+8\text{m}^2 \times 78\% \times 1.5355\text{m} \times 1\text{E}+6\text{g}/\text{m}^3 \times 4.78\text{J}/\text{g}$		
Energy	8.01E+14	J	1.68E+08 m ³
Subtotal ET ^{2*}	1.78E+15	J	3.71+08 m ³
ET from rain 0.072 by energy ^{3*}	1.27E+14	J	2.65E+07 m ³
ET from river 0.928 by energy ^{3*}	1.65E+15	J	3.51E+08 m ³
8 Water stored in peat			
Depth addition of peat	0.04	m	Zuo et al. 2004
Water content ratio	0.57		Zuo et al. 2004
Density	1.00E+06	g/m ³	
Gibbs free energy of rain & river	4.63	J/g	At avg. annual temperature
Energy	Vol. of rain water× Gibbs free energy of rain water+ vol. of river water× Gibbs free energy of river water		
Subtotal water stored ²	2.61E+13	J	5.63E+06 m ³
Fraction from rain 0.066 by vol. ^{4*}	1.76E+12	J	3.72E+05 m ³
From river water 0.934 by vol. ^{4*}	2.43E+13	J	5.26E+06 m ³
9 Cost for harvest per MT <i>Phragmites</i>	100	RMB/MT	
Exchange Ratio	8.3	\$ /RMB in 2000	
Harvest quantity of <i>Phragmites</i>	20000	MT/y	
Formulation of Purchased input for harvest <i>Phragmites</i>	Cost for harvest per MT <i>Phragmites</i> /Exchange Ratio× quantity harvested		
Purchased input	2.41E+05	\$ in 2001	
10 *NPP of <i>Phragmites</i>	$1.07\text{E}+08\text{m}^2 \times 2.72\text{E}+03\text{g}/\text{m}^2/\text{y}$		Zuo et al. 2004
	2.91E+11	g	
*NPP of <i>Aeluropus</i> and <i>Imperata</i>	$1.40\text{E}+08\text{m}^2 \times 2.45\text{E}+03\text{g}/\text{m}^2$		Zuo et al. 2004
	3.43E+11	g	
Subtotal	6.34E+11	g	
Standard energy value	4.00E+00	kcal/g	
Energy ²	1.06E+16	J	
*Energy of <i>Phragmites</i> harvested	3.35E+14	J	
*Energy of left NPP	1.03E+16	J	
11 Peat depth	0.85	m	Zuo et al. 2004
Density	0.7	g/cm ³	Zuo et al. 2004
Organic C content ratio	0.105		Odum 1996
Standard energy value of C	11	kcal/g	Coultas and Calhoun 1976
Turn over time	188	a	Zuo et al. 2004
Energy formula	deposition area ×depth ×density × C content ratio ×Gibbs free energy of the C /turn over time		
Energy	3.78E+15	J	
12 Annual production of benthic fauna	378	g wwt./m ²	Dong et al. 2005
Standard energy value	3767	J/g	USDA Nutrient Data Laboratory

	Energy formula	Area×biomass per area×standard energy value	
	Energy	3.52E+14 J	
13	River water outflow	1.38E+16 J	3.04E+09 m ³
14	Rain infiltration [†]	1.07E+15 J	

IV. *Spartina* and *Suaeda*

	Area ²	5.17E+08 m ²	
	Area of <i>Spartina</i>	2.51E+08 m ²	
	Area of <i>Suaeda</i>	2.66E+08 m ²	
1	Mean annual solar radiation	1.19E+06 kcal/m ²	Zhang,1998
	Albedo	0.3	Zuo et al. 2004
	Energy formula	area× average of solar radiation×(1-Albedo) ×4186 J/kcal	
	Energy	1.80E+18 J	
2	Wind velocity (metric)	5 m/s	Zhu et al. 2004
	Geostrophic wind	8.34 m/s	Reiter 1969
	Air density	1.23 kg/m ³	
	Drag coefficient	2.00E-03	Garratt 1977
	Sec/year	3.15E+07 s	
	Energy of Wind	area × density × drag coefficient × (geostrophic wind velocity) ³ ×sec/yer	
	Energy	2.32E+16 J	
3	Earth heat flux	75 mW/m2	http://www.heatflow.und.edu
	Energy	heat flux ×area× seconds/y	
	Energy	1.22E+15 J	
4	Rainfall	1.025 m	
	Mean elevation	2 m	
	Density	1.00E+03 kg/m ³	
	Gravity	9.8 m/s ²	
	Geopotential of rain	area× mean elevation × rainfall × density × gravity	
	Energy	1.04E+13	
5	Gibbs free energy of rain	4.72 J/g	At mean annual temperature
	Chemical potential of rain	(area+0.5 prograded area) × rainfall × density × Gibbs free energy	
	Energy	2.50E+15 J/y	5.30E+08 m3
6	River water inflow	1.38E+16 J/y	From III.13
7	Evapotranspiration	3.5 L/m2/growth day	Hussey and Odum,1992
	Growth days (without frost)	210 day	
	Density	1.00E+03 g/l	
	Subtotal energy ET ^{2*}	1.85E+15 J	3.80E+08 m3
	From rain fraction 0.155 by energy ^{3*}	2.83E+14 J	5.81E+07 m ³
	From river water 0.845 by energy ^{3*}	1.57E+15 J	3.28E+08 m ³

8	Water stored in peat			
	Depth addition of peat	0.04	m	Zuo et al. 2004
	Water content ratio	0.57		Zuo et al. 2004
	Density	1.00E+06	g/m ³	
	Energy formula	Vol. Of rain water× Gibbs free energy of rain water+ vol. Of river water× Gibbs free energy of river water		
	Subtotal energy of water stored ²	5.47E+13	J	1.18E+07 m ³
	From rain fraction 0.153 by vol. ^{4}	8.25E+12	J	1.75E+06 m ³
	From river water 0.847 by vol. ^{4}	4.65E+13	J	1.00E+07 m ³
9	Tides per year	707		
	Mean height	1.7	m	
	Density	1.025E+03	kg/m ³	
	Gravity	9.800E+00	m/s ²	
	Formula for energy of tide	area× 0.5 ×(tides/y)× (height) ² × density × gravity		
	Energy	5.50E+15	J	
10	NPP of <i>Spartina</i>	area×2.60E3g/m ²		Zuo et al. 2004
		6.53E+11	g	
	NPP <i>Suaeda</i>	2.66E+08m ² ×5.59E+02g/m ²		Zuo et al. 2004
		1.49E+11	g	
	Subtotal salt marsh NPP ²	8.01E+11	g	
	Standard energy value	4.00E+00	kcal/g	
	Energy	1.34E+16	J	
11	Peat depth	0.85	m	Zuo et al. 2004
	Density	0.7	g/cm ³	Zuo et al. 2004
	Organic C content ratio	0.105		Zuo et al. 2004
	Standard energy value	11	kcal/g C	
	Turn over time	188	y	Zuo et al. 2004
	Energy of peat deposited	area ×depth × density × organic content ratio ×Gibbs free energy of the organic matter /turn over time		
	Energy	7.91E+15	J/y	
12	Annual production of benthic fauna	378	g wwt./m ²	Dong et al. 2005
	Standard energy value	3767	J/g wwt.	
	Formula for energy of benthos	(area+0.5 prograded area)×biomass per area×standard energy value		
		7.36E+14	J/y	
13	River water outflow	1.22E+16	J/y	2.71E+09 m3
14	Rain infiltration [†]	2.21E+15	J/y	4.62E+08 m3

V. Salt pans

	Area	3.25E+08	m ²	
1	Mean annual solar radiation	1.19E+06	kcal/m ² /y	Zhang,1998
	Albedo	0.3		Zuo et al. 2004

	Formula for energy from the sun	area×average solar radiation× (1-Albedo) ×4186 J/kcal		
	Energy	1.13E+18	J/y	
2	Wind velocity (metric)	5	m/s	Zhu et al. 2004
	Geostrophic wind	8.34	m/s	Reiter 1969
	Air density	1.23	kg/m ³	
	Drag coefficient	1.00E-03		Garratt 1977
	Sec/year	3.15E+07	J	
	Formula for energy from the wind	area × density × drag coefficient × (geostrophic wind velocity) ³ ×sec/y		
	Energy	7.30E+15	J/y	
3	Earth heat flux	75	mW/m2	http://www.heatflow.und.edu
	Energy formula	heat flux ×area × seconds/y		
	Energy	7.69E+14	J	
4	Rainfall	1.025	m/y	
	Mean elevation	2	m	
	Density	1.00E+03	kg/m ³	
	Gravity	9.8	m/s ²	
	Geopotential of rain	area × mean elevation × rainfall × density × gravity		
	Energy	6.53E+12		
5	Formula for weight of rain water	Area×rainfall×density		
	Mass	3.33E+14	g	
	Salt yield	9.36E+11	g	Wang et al. 2001
	Waste salt	9.36E+10	g	
	Salts in waste brine	6.32E+11	g	
	Salt required	1.66E+12	g	
	Mean salinity of seawater	3.09E+04	g/m ³	
6	Formula for seawater required	salt dissolved in seawater/mean salinity of seawater		
	Volume	5.38E+07	m ³	
7	Evaporation	1.5355	m/y	Yancheng Reserve Committee,2000
	Density	1.00E+06	g/m ³	
	Gibbs free energy rain	4.87	J/g	In the warm seasons
	Energy	area×evaporation×density×Gibbs free energy		
		2.43E+15	J	
8	Fuels and goods required per g salt	5.09E+07	sej/g salt yield	Babic 2005, adjusted to 9.26 baseline
	Total fuels and goods	4.77E+19	sej/yr	
9	Labor	22.4	J/g salt yield	Babic 2005, adjusted to 9.26 baseline
	Labor cost	2.09E+13	J/yr	
10	Salt yield	9.36E+11	g	Wang et al. 2001
11	Annual production of benthic fauna	241	g wwt./m ²	Dong et al. 2005
				USDA Nutrient Data Laboratory
	Standard energy value	3767	J/g	“Food Composition and Nutrition.” http://www.nal.usda.gov/fnic/cgi-bin/nut_search.pl

Formula for energy of benthos

area×biomass per area×dry ratio×standard energy value

Energy 2.95E+14 J

VI. Mud flats

Area 2.06E+09 m²

1 Mean annual solar radiation 1.19E+06 kcal/m²/y Zhang,1998

Albedo 0.3 Zuo et al. 2004

Energy area×average of solar radiation×(1-Albedo) ×4186 J/kcal

7.19E+18 J/y

2 Wind velocity (metric) 5 m/s Zhu et al. 2004

Geostrophic wind 8.34 m/s Reiter 1969

Air density 1.23 kg/m³

Drag coefficient 1.00E-03 Garratt 1977

Sec/year 3.15E+07 J

area×density×drag coefficient×(geostrophic wind velocity)³×sec/yr

Energy 4.64E+16 J

3 Earth heat flux 75 mW/m² <http://www.heatflow.und.edu>

Energy heat flux ×area× seconds/y

Energy 4.88E+15 J

4 Rainfall 1.025 m

Mean elevation 2 m

Density 1.00E+03 kg/m³

Gravity 9.8 m/s²

Geopotential of rain area× mean elevation × rainfall × density × gravity

Energy 4.14E+13

5 Gibbs free energy of rain 4.72 J/g At mean annual temperature

Formula for rain chemical potential area× rainfall × density × Gibbs free energy

Energy 9.98E+15 J 2.11E+09 m³

6 River water inflow 2.71E+15 g From IV.13 above

Salinity of mixed water near beach 2.20E+04 g/m³ Yancheng Reserve Committee,2000

Formula for Gibbs free energy (8.314/mole/deg)(287K)/(18g/mole)*ln((1E+06-750)ppm/(1E+06-22000ppm))

Gibbs free energy river water 2.85 J/g

Energy 7.71E+15 J

7 Wave

Shore length 5.82E+05 m

Absorption ratio 0.125 Odum 1996, Qin et al. 2000

Density 1.025E+03 kg/m³

Mean wave height 1 m

Gravity 9.8 m/s

Velocity 2.6 m/s

Formula for wave energy		shore length×absorption ratio×density×gravity×(height) ² ×velocity×3.15×10 ⁷ s/y	
	Energy	5.99E+16	J/y
8	Tides per year	707	
	Mean height	1.7	m
	Density	1.025E+03	kg/m ³
	Gravity	9.800E+00	m/s ²
		area elevated × 0.5 ×(tides/y)× (height) ² × density × gravity	
	Energy	2.12E+16	J/y
9	NPP of Phytoplankton	5320	g/m ² Zuo et al. 2004
	Standard energy value	5	kcal/g
		area×average NPP of Phytoplankton ×standard energy	
	Energy	2.30E+17	J
10	Annual production of Benthic fauna	365	g/m ² Dong et al. 2005
			USDA Nutrient Data Laboratory
			“Food Composition and Nutrition.”
			http://www.nal.usda.gov/fnic/cgi-bin/nut_search.pl
		area×biomass per area×standard energy value	
	Energy	2.84E+15	J/y

Waterfowls

1	Purchased forage for waterfowl (mainly corn)	5.00E+06	g/y	Dong et al. 2005
	Energy per weight	19736	J/g	Campbell et al. 2005
	Energy	9.87E+10	J	
2	Estimated number of birds	7.54E+06	ind.	Yancheng Reserve Committee,2000
	Mean weight	800	g/ind.	Qin et al. 2000
	Time of stay (years)	0.5		Yancheng Reserve Committee,2000
	Dry weight ratio	0.2		
	Standard energy value	4.04	kcal/g	Typical value for duck
	Number×avg. weight×time of stay×dry wwt ratio×standard energy value			
	Energy	1.02E+13	J	
3	Daily food requirement of waterfowl	food weight/average biomass of waterfowl/day		
	Daily ration	8/45	g/g.day	Loesch et al. 2002,
	Benthic fauna eaten by waterfowl	Number×avg. weight×Stay in days×daily ration-artificial forage-rice		
	Weight Fauna consumed ⁵	1.96E+11	g	
	Fraction of benthic fauna eaten by waterfowl	16.79%		

¹Assumes all of the farmland is used for rice planting and is irrigated.

²Sub-items included.

³ Take the available energy of river water and rain water as the weighting factor.

⁴ Take the available volume of river water and rain water as the weighting factor.

⁵ 2.25E+11 g food required and 1.52E+12 g produced.

* Assume the chance that a parcel of river or rain water would be used for evaporation, evapotranspiration or absorption into the peat was dependent only on the quantities of each that were available.

† Assume all of the rain water left after evapotranspiration was assumed to infiltrate into the ground water in the relatively flat

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