



**British
Geological Survey**

NATURAL ENVIRONMENT RESEARCH COUNCIL

Applied geoscience for our
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celebrating
175
years

IMAGES

British Geological Survey

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(with assistance of Prof S Garvey!)

www.bgs.ac.uk

IMAGES AGM, Warwick University

21 Nov. 2016

Review

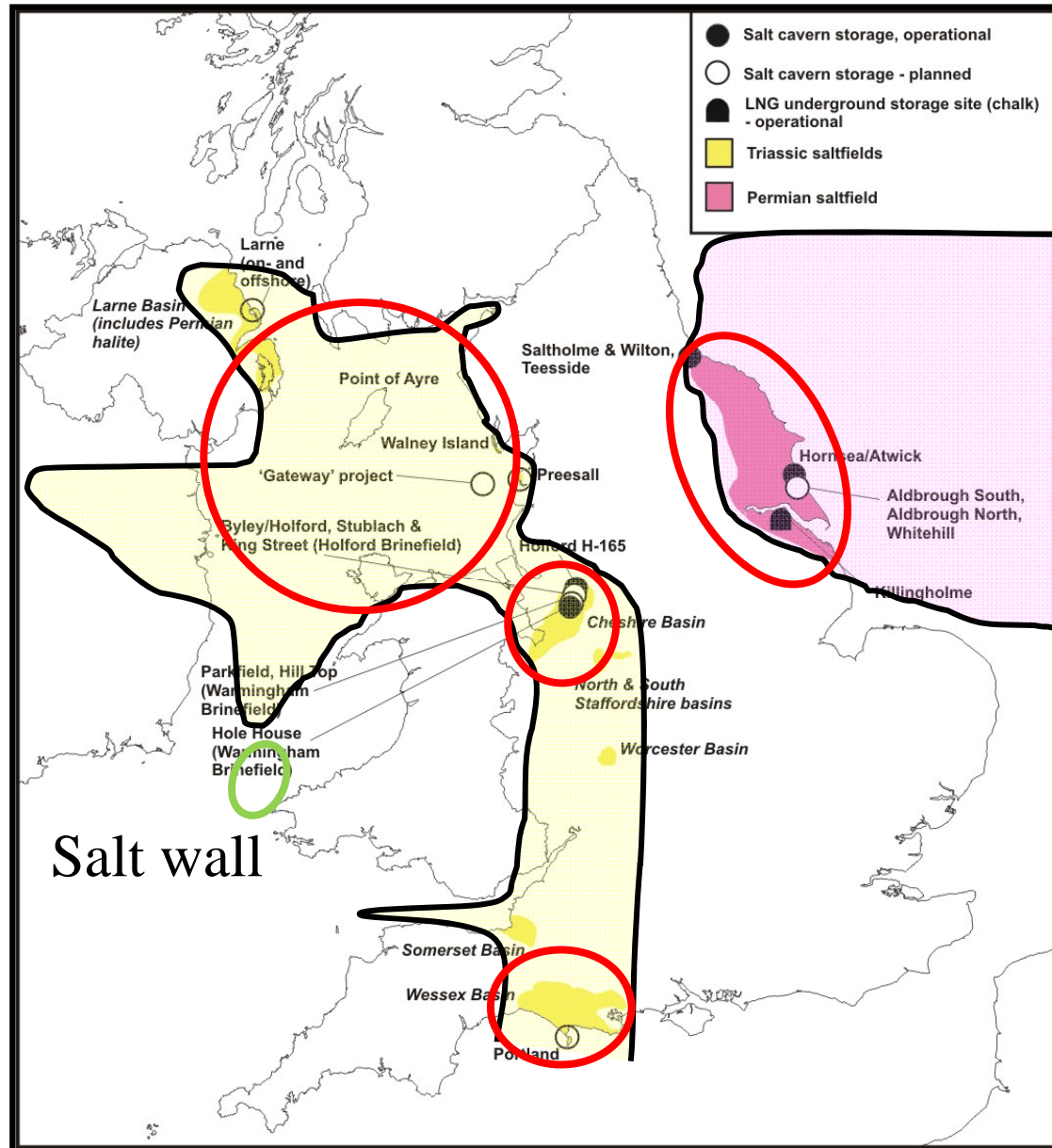
- Work on Gateway core
 - Dissolution experiments
 - Min/pet descriptions
 - Series of papers planned –various draft stages
- Stress rig work – now on hold
- Cavern/exergy volume estimates
 - GIS development
 - Exergy calculations – for all UK salt basins now
 - Number of papers planned, based on work/results
 - GIS – processes etc.
 - Volume/exergy calculations – to include derivation of insoluble content
- Funding & future work – low and now curtailed – mainly writing up



UK Salt Cavern storage facilities & area of study

Outline IMAGES work on UK salt basin storage potential

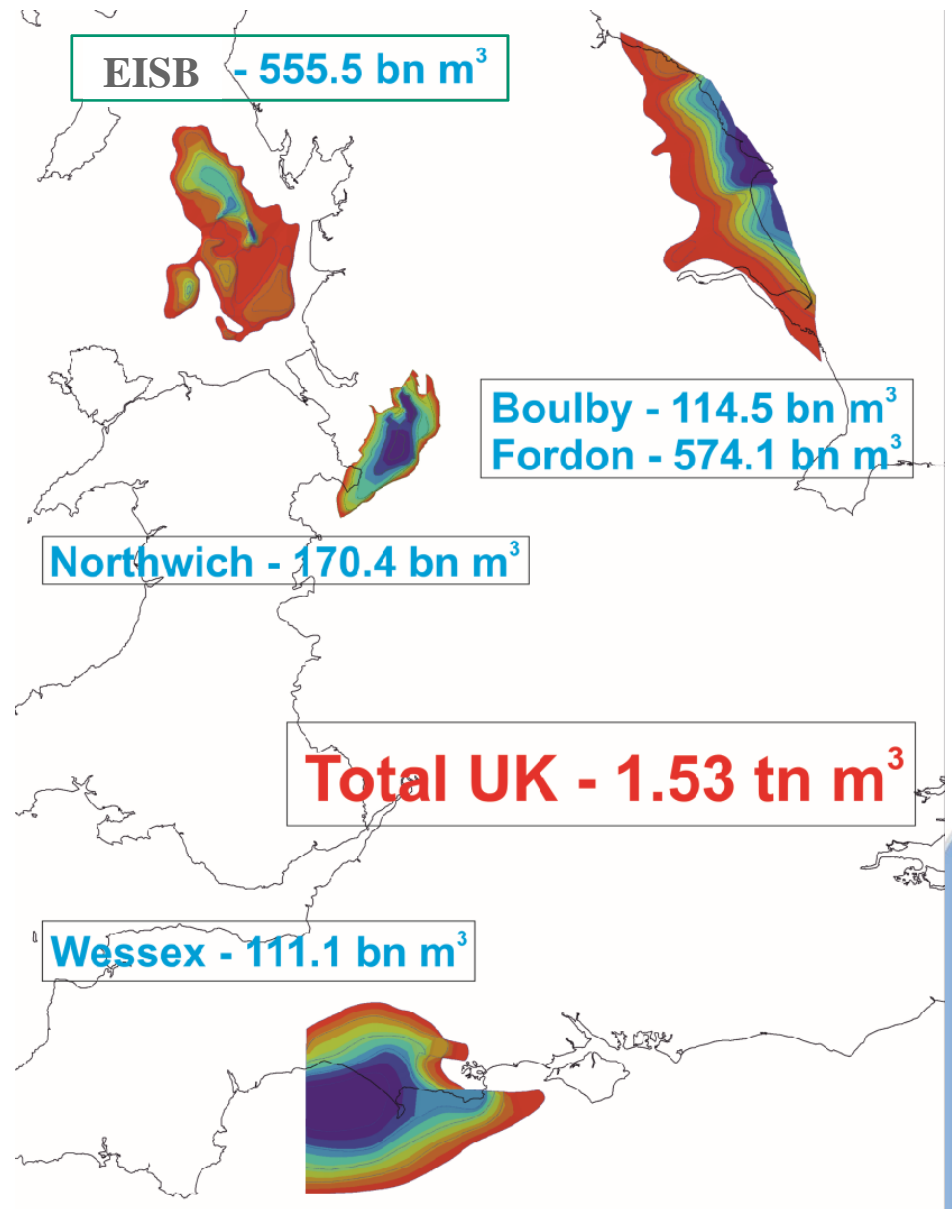
- Mapping of main onshore salt basins with potential
 - Top & base salt and thickness maps
 - Cheshire Basin
 - East Irish Sea
 - Wessex Basin
 - East Yorkshire
- GIS development & processes to derive volumes
 - To model salt surfaces - derive volumes
 - Model cavern locations & derive storage volumes
 - Theoretical
 - More realistic – buffering out areas – still over estimate
 - Based on experienced gained in gas storage projects
- Illustrate with Cheshire Basin storage potential
 - Number of potential caverns
 - Theoretical and more realistic cavern volumes
 - ‘gas’ storage volumes & Exergy



UK salt basins – volumes/resource

Used boreholes, derived salt maps & GIS to determine

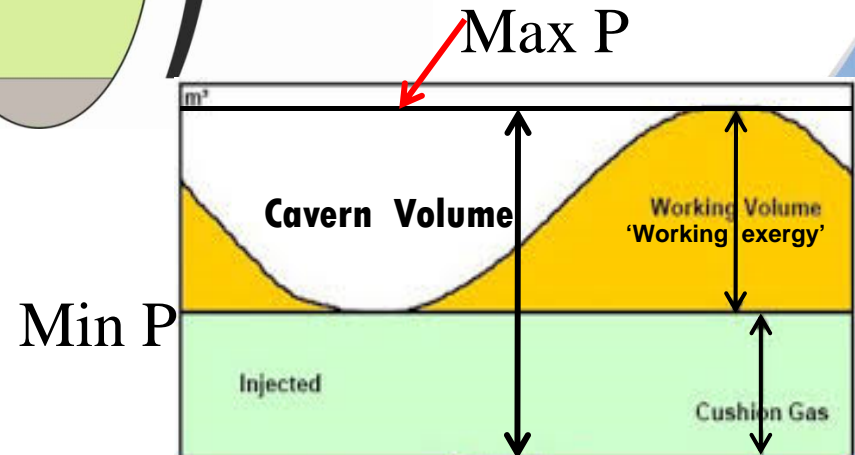
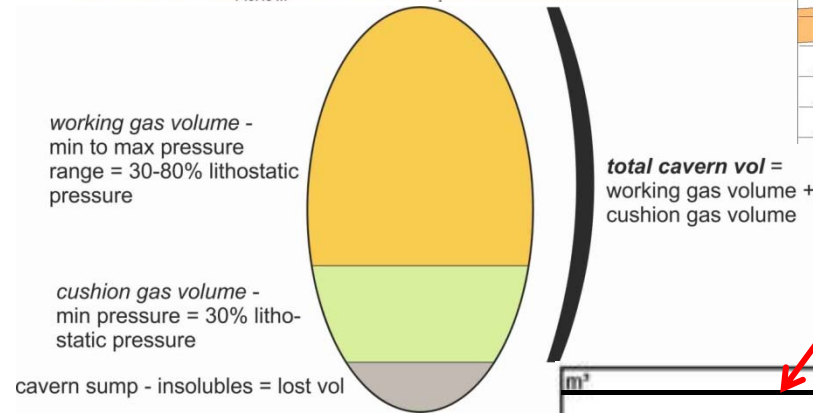
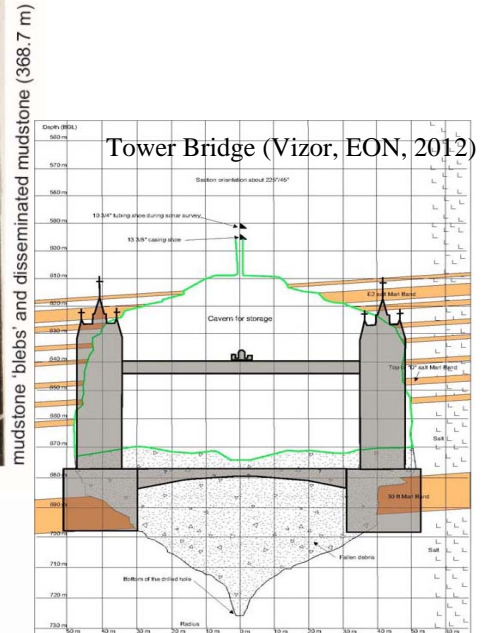
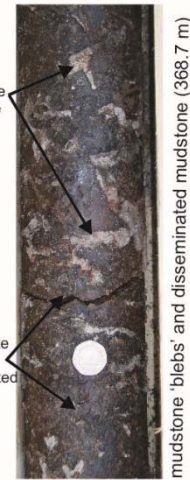
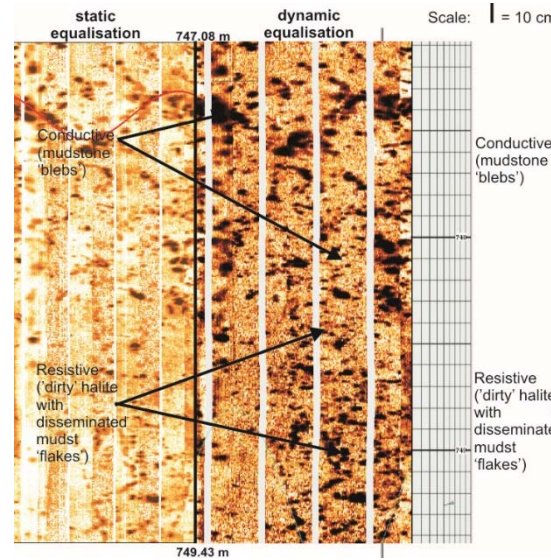
- Salt volumes in basins
- Look at theoretical cavern numbers & volumes
- Then buffer out areas & derive more realistic storage volumes
- Illustrate with Cheshire Basin example



Salt cavern storage – some basics

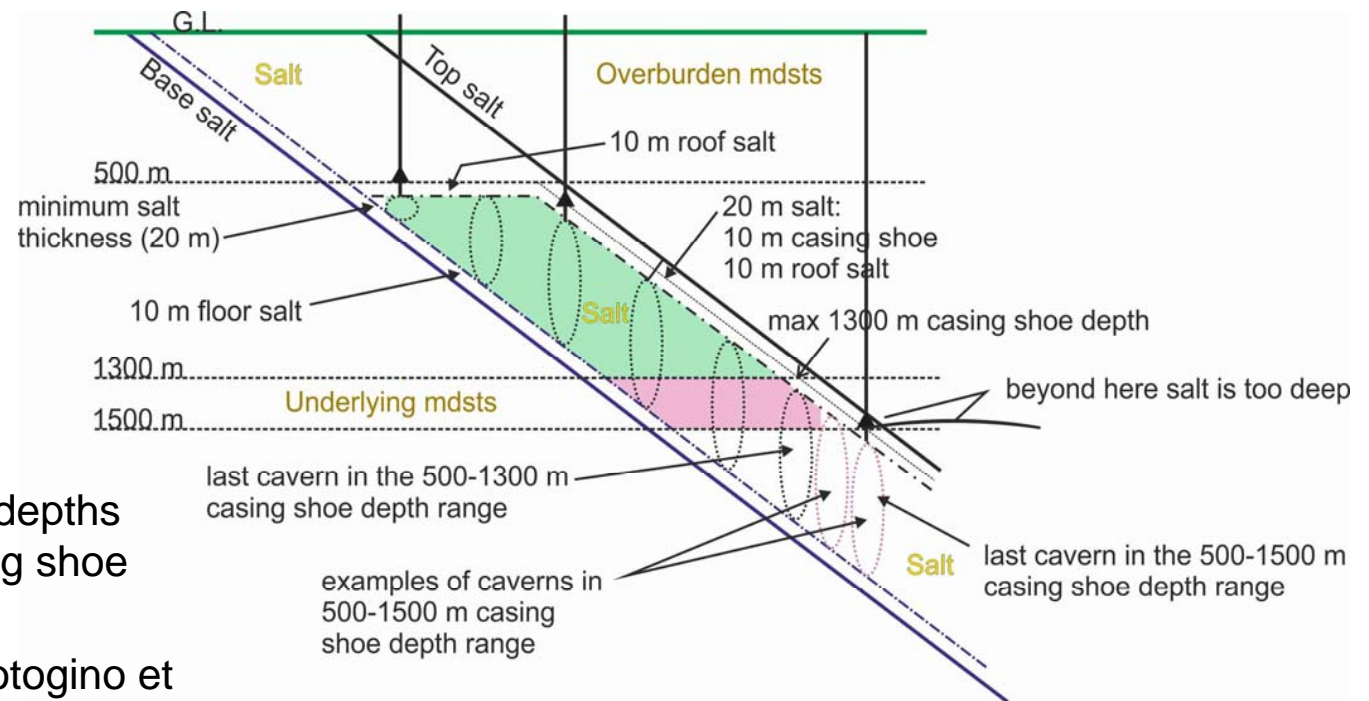
Certain fundamentals apply

- Contains insolubles – disseminated & beds
 - sump area
- Salt creeps (flows)
- Maintain cavern stability & work within
 - Min P – supports cavern walls ~30%
 - Max P – prevents fracturing ~75-80%
 - Max P gradient
 - Dependent upon depth
- In terms of cavern volume, then determines you have
 - Total cavern volume comprising
 - Working gas volume (min-max. P range)
 - Cushion gas volume (up to min P)



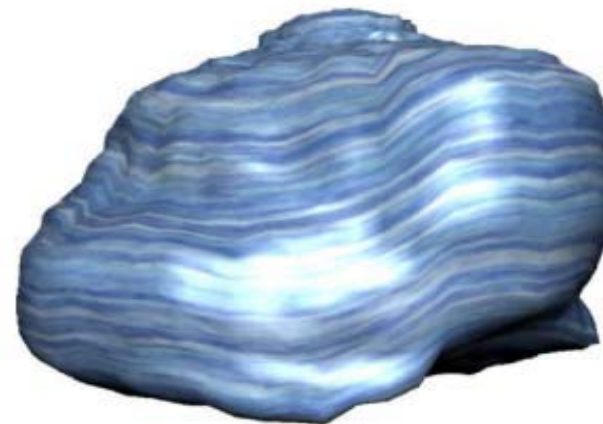
Salt cavern & energy storage volumes

- details of analysis



Cavern volumes at storage depths with depths of storage/casing shoe set from:

- 1st set based on Crotogino et al. – 500 m – 1300 m depth range
- 2nd set based on Gaelectric's Larne project – max 1500 m depth
- 3rd set based on gas storage experience – 250 m – 1300/1500 m



Salt cavern & energy storage volumes

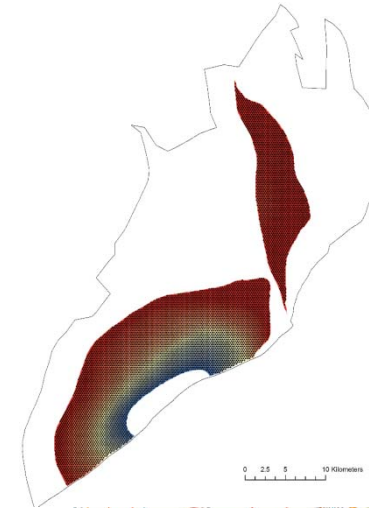
- example of process in Arc GIS

Borehole data
contoured up

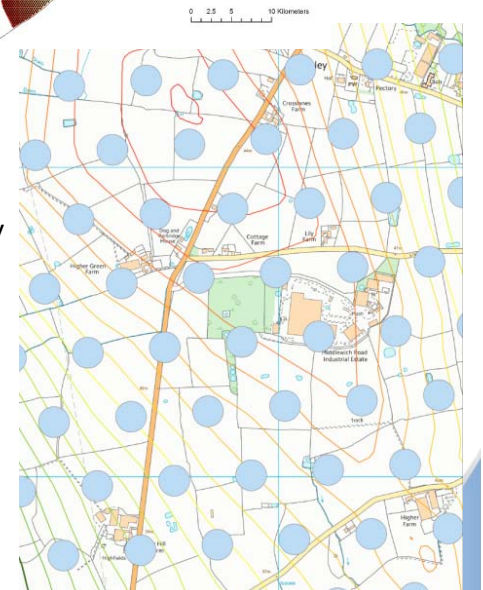


Maps –
Top, base,
thickness

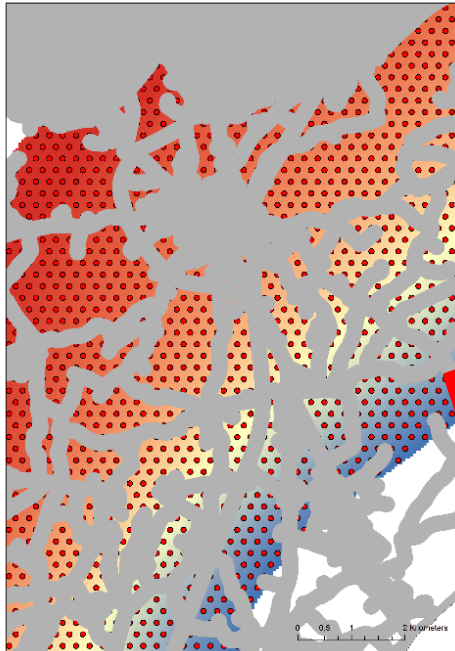
Cut top salt map
to depth range
(500-1300 m &
500-1500 m)



Generate cavern
locations & query
against salt
depth and
thickness maps



Apply buffers &
derive remaining
caverns/volumes



Generate theoretical
caverns/volume data

UNIQUE_ID	COUNT	AREA	MIN	MAX	RANGE	MEAN	ST D	SUM	Ellipsoid Volume	Cylindrical Volume
4130	8	2501.3	200.6	201.8	1.2	201.1	0.5	1609.1	335239.3	1579778.0
4131	2	625.3	200.2	200.5	0.4	200.4	0.2	400.7	333946.2	1573684.3
4182	23	7191.3	202.6	209.0	6.4	206.0	1.7	4738.6	343374.8	1618115.4
4183	22	6878.6	209.4	213.9	4.5	211.7	1.2	4658.3	352900.7	1663005.6

- 100 m diameter (R=50 m)
 - Hexagonal pattern
- 150 metre thick salt pillars – 3R
- Min 20 m roof salt – casing pt.
 - 10 m into salt
 - 10 m base salt

Basic categories now completed

- Total UK – theoretical volumes and unrealistic
- Reduced – buffered areas against various datasets
 - Cultural - infrastructure
 - Geological – main faults, insoluble content, wet rockhead etc
 - Still unrealistic
- Further reduced volume by
 - Taking only caverns of 100 m or greater height
 - 1% of that figure
- Still very large UK exergy storage potential

Salt cavern volumes and Exergy estimates

Cut Cavern ID	Original Cavern ID	Cavern presence query	Unshere d Salt Top (m)	Unshere d Salt Base (m)	Salt top depth (m)	Salt base depth (m)	Base of Cavern Depth (m)	Cavern height (m)	Salt casing shoe thickness above sak (m)	Overtur den thickness above sak (m)	Casting shoe depth (m)	Top Cavern Depth (m)	Lithosta tic pressur e @ casing shoe (bar)	Cylindri cal Volume (m3)	Shape Correct ion (m3)	Mean Insolubl e Residue (maps)	Insolubl e NDT Svept	Bulking Factor (std)	Insolubl e Volume m3 (8)	Temper ature at Casing Shoe (10) (C)	Temper ature at Casing Shoe (11) (F)	Temper ature at Casing Shoe (12) (C)	Temper ature at Casing Shoe (13) (F)	Lithosta tic Pressur e at Casing Shoe (11) (Bar)	Lithosta tic Pressur e at Casing Shoe (12) (psi)	Max Operati ng Pressur e at Casing Shoe (14) (M)	Min Operati ng Pressur e at Casing Shoe (13) (N)	Z @ max op pressur e (15a)	Z @ min op pressur e (15b)	Temper ature Correct ion (16)	Pressur e Correct ion (17)	Temp & Pressur e Corrected Cavern Volume (18) m3	Cavern Total Gas Volume corrected for compressibilit y (19) m3	Cavern Cushion Gas Volume corrected for compressibilit y (20) m3	Cavern Working Gas (21) m3 @ Standard Conditions	Max Pressur e Ratio	Min Pressur e Ratio	Max Exergy Present (MWh)	Min Exergy Present (MWh)	TOTAL VALUE OF EXERGY STORE (MWh)					
1	134	TRUE	-446.3	-545.8	446.29	545.81	535.81	25.812	53.711	446.29	500	510	116.67	202723	0.7	14906	0.25	0.25	0.2133	15	0.08	11348	130558	17.615	63.707	523.71	116.67	1691.7	96.833	1404.1	35	507.5	1.00	1.00	0.9329	0.9864	127870.33	12382058.25	4475442.741	7908615.509	95.567	34.542	1253.8	326.356	927.443
2	135	FALSE	-460.5	-553.3	460.46	553.94	543.94	39.94	39.94	460.46	500	510	116.94	313691	0.7	219584	0.25	0.25	0.2133	15	0.08	17580	202024	17.615	63.707	523.71	116.94	1695.7	97.064	1407.4	35.083	508.71	1.00	1.00	0.9329	0.9864	197864.95	19205490.66	6941743.61	12263747.04	95.794	34.624	1946.02	506.658	1438.36
3	262	TRUE	-490.5	-592.2	490.47	592.19	550.19	40.192	39.531	490.47	500	510	116.94	319570	0.7	220969	0.25	0.25	0.2133	15	0.08	17671	203299	17.615	63.707	523.71	116.94	1695.7	97.064	1407.4	35.083	508.71	1.00	1.00	0.9329	0.9864	199112.84	19239959.3	6965529.144	1234119.15	95.795	34.625	1959.3	509.855	1448.44
4	263	FALSE	-475.5	-575.1	475.47	575.14	555.14	55.136	24.533	475.47	500	510	117.24	439034	0.7	303124	0.25	0.25	0.2133	15	0.08	24240	278883	17.615	63.707	523.71	117.24	1700	97.308	1411	35.172	509.99	1.00	1.00	0.9329	0.9864	273141.94	26578920.34	9606838.673	16372081.67	96.036	34.712	2695.02	701.841	1933.17
5	264	TRUE	-490.4	-590	490.37	590.03	580.03	69.1	10	490.37	500.37	510.37	117.61	542712	0.7	379899	0.25	0.25	0.2133	15	0.08	30380	349519	17.622	63.719	523.72	117.61	1705.4	97.618	1415.5	35.283	511.61	1.00	1.00	0.9329	0.9864	342322.8938	33415990.84	12078068.98	21937921.86	96.341	34.822	3391.33	883.457	2507.87

Temperature at Casing Shoe (°R)	Pressure at Casing Shoe (Bar)	Lithostatic Pressure at Casing Shoe (psi)	Max Operating Pressure at Casing Shoe (Bar)	Max Operating Pressure at Casing Shoe (14a) (psi)	Min Operating Pressure at Casing Shoe (13) (Bar)	Min Operating Pressure at Casing Shoe (14b) (psi)	Temperature Correction (16) (OP)	Temperature Pressure Correction Volume (17)	Temp & Pressure Corrected Cavern Volume (18) m3	Cavern Total Gas Volume corrected for compressibility (19) m3	Max Pressure Ratio	Min Pressure Ratio	Max Exergy Present (MWh)	Min Exergy Present (MWh)	TOTAL VALUE OF EXERGY STORE (MWh)
523.707	116.891	1694.919	97.019499	1406.7827	35.067289	508.47569	0.992922	0.986395	127870.3253	12405914.91	96	35	1,257	327	930
523.707	116.8853	1694.8371	97.014814	1406.7148	35.065595	508.45113	0.992922	0.986395	197864.9481	19195831.18	96	35	1,945	506	1,438
523.707	117.1801	1699.1114	97.259479	1410.2624	35.154029	509.73342	0.992922	0.986395	199112.8408	19365611.22	96	35	1,963	511	1,452
523.707	117.4726	1703.3531	97.50228	1413.7831	35.241788	511.00593	0.992922	0.986395	273141.944	26631962.37	96	35	2,702	704	1,998
523.707	116.8993	1695.0397	97.026409	1406.8829	35.069786	508.5119	0.992922	0.986395	342322.8938	33214361.09	96	35	3,365	876	2,489

- Example of spreadsheet with various categories – mostly based upon gas storage experience....lithostatic pressure at casing shoe, geometric and reduced cavern volumes – insolubles, bulking factor, shape correction factors (70%) etc.
- For each cavern location
- Following examples for categories:
 - Cheshire Basin
 - av. 25% insoluble & mapped insolubles for comparison
 - 500-1500 m depth range
 - UK salt basins



Cavern volumes and exergy estimates

– theoretical and initially buffered

Salt Basin (500-1500 m)		Nos. caverns	All caverns				Nos. caverns	Remaining caverns			
			Temp & Pressure Corrected Cavern Volume (m ³)	Max Exergy Present (MWh)	Min Exergy Present (MWh)	WORKING EXERGY (MWh)		Temp & Pressure Corrected Cavern Volume (m ³)	Max Exergy Present (MWh)	Min Exergy Present (MWh)	WORKING EXERGY (MWh)
Cheshire Basin	Sum	7835	5,171,542,806	81,938,653	22,144,592	59,794,061 (59.8 TWh)	2,099	1,386,567,591	24,054,650	6,535,016	17,519,633 (17.5 TWh)
	Av		660,057	10,458	2,826	7,632		660,585	11,460	3,113	8,347
	Max		1,161,437	22,733	6,391	16,342		1,154,975	22,466	6,311	16,155
	Min		100,073	973	253	720		113,658	1,095	284	811
	Mapped insolubles		4,543,074,364			50,637,011 (50.6 TWh)		1,187,511,879			14,493,764 (14.5 TWh)



Cavern volumes and exergy estimates – initially buffered to >100 m height & 1%

		Remaining buffered caverns					Caverns > 100 m height					1% of buffered & >100 m cavern height (MWh)
		Nos. caverns	Temp & Pressure Corrected Cavern Volume (m ³)	Max Exergy Present (MWh)	Min Exergy Present (MWh)	WORKING EXERGY (MWh)	Nos. caverns	Temp & Pressure Corrected Cavern Volume (m ³)	Max Exergy Present (MWh)	Min Exergy Present (MWh)	WORKING EXERGY (MWh)	
Salt Basin (500-1500 m)												
Cheshire Basin	Sum	2,099	1,386,567,591	24,054,650	6,535,016	17,519,633 (17.5 TWh)	1,618	1,222,640,961	21,362,432	5,805,197	15,557,235 (15.6 TWh)	155,572 (0.2 TWh)
	Av		660,585	11,460	3,113	8,347		755,650	13,203	3,588	9,615	
	Max		1,154,975	22,466	6,311	16,155		1,154,975	22,466	6,311	16,155	
	Min		113,658	1,095	284	811		470,638	4,689	1,218	3,471	
	Mapped insolubles		1,187,511,879			14,493,764 (14.5 TWh)		1,056,261,347			12,964,277 (13 TWh)	129,643 (0.13 TWh)

Important: this is the **STATIC** working exergy – once only fill/empty Caverns will have a number of fill/empty cycles, meaning the **DYNAMIC** working exergy or capacity is many times greater



UK exergy storage summary

	Total theoretical UK cavern volume/exergy			Remaining buffered cavern volume/exergy			Caverns > 100 m height remaining volume/exergy			1% of buffered & >100 m cavern height (MWh/GWh /TWh)
	Nos. caverns	Temp & Pressure Corrected Cavern Volume (m3)	WORKING EXERGY (MWh/TWh)	Nos. caverns	Temp & Pressure Corrected Cavern Volume (m3)	WORKING EXERGY (MWh/TWh)	Nos. caverns	Temp & Pressure Corrected Cavern Volume (m3)	WORKING EXERGY (MWh/TWh)	
Salt Basin (500-1500 m)										
<i>Cheshire Basin</i>	7,835	5,171,542,806	59,794,061/ 59.8	2,099	1,386,567,591	17,519,633/ 17.5	1,618	1,222,640,961	15,557,235/ 15.6	155,572/ 155/ 0.16
<i>East Irish Sea (only 1300 m)</i>	15,266	13,331,631,381	119,574,768/ 119.6	11,331	10,363,247,585	95,510,377/ 95.5	7,820	9,341,062,220	88,283,579/ 88.3	882,836/ 882.8/ 0.88
<i>Wessex Basin</i>	42,872	36,850,767,139	762,490,791/ 762.5	26,718	26,915,006,634	553,519,539/ 553.5	22,225	25,502,413,470	525,612,043/ 525.6	5,256,120/ 5256/ 5.3
<i>East Yorks - Boulby Halite</i>	12,849	1,744,850,197	36,591,764/ 36.6	3,177	408,740,854	9,164,334 9.16	0			
<i>East Yorks - Fordon Evaporites</i>	19,506	12,642,897,085	325,957,285/ 326	9,204	7,444,753,648	188,332,407/ 188.3	5,242	6,548,138,512	166,386,531/ 166.4	1,663,865/ 1663.8/ 1.7
Totals (MWh)	98,328	69,741,688,608	1,304,408,670	52,529	46,518,316,312	864,046,291	36,905	42,614,255,164	795,839,388	7,958,394
Totals (GWh)			1,304,408			864,046			795,839	7,958
Totals (TWh)			1,304			864			796	8

~33% volume/exergy loss in total (66% in Cheshire Basin)

~8-10% volume/exergy loss



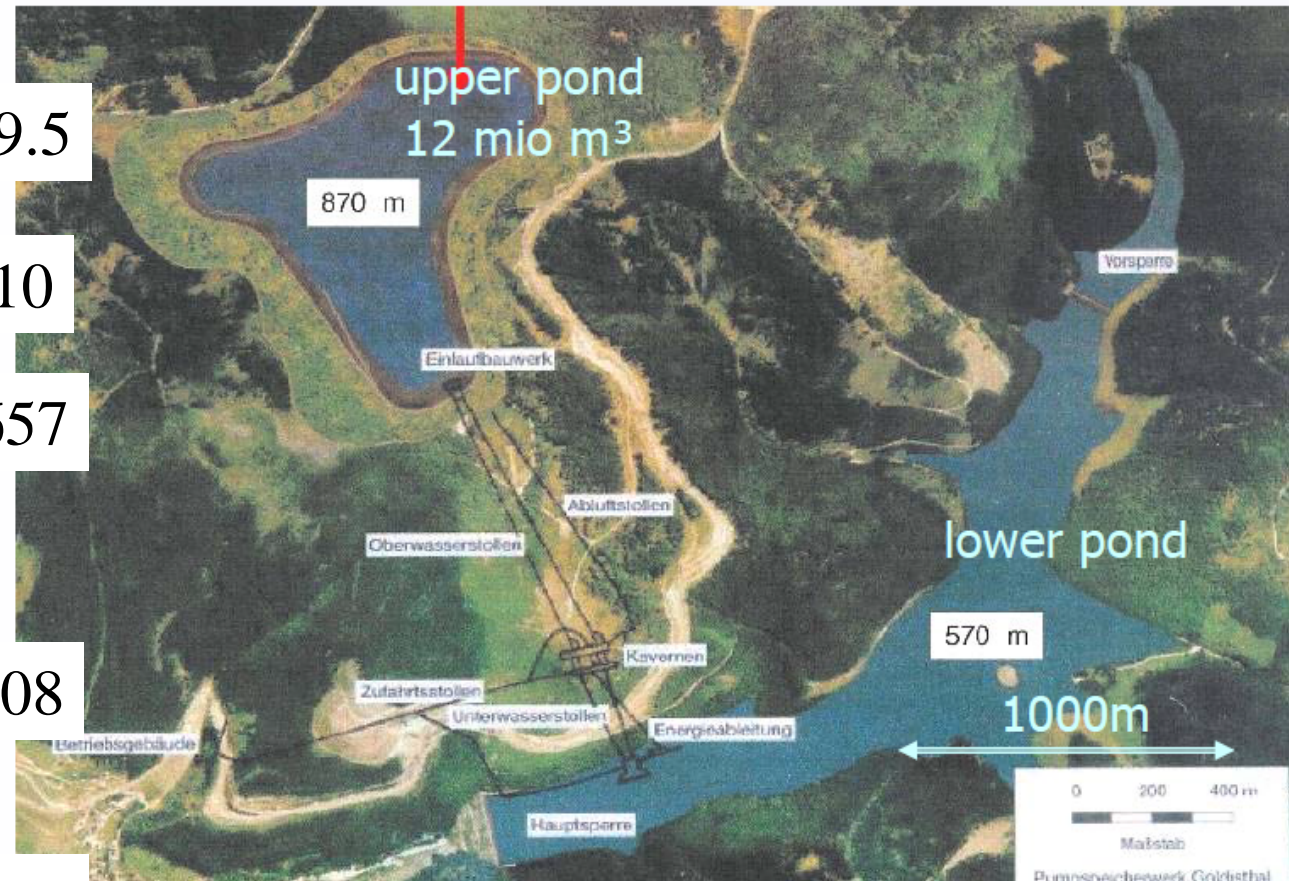
Summary/context

Salt Basin (500-1500 m)	1% of buffered & >100 m cavern ht (MWh/ GWh/ TWh)
Cheshire Basin	155,572/ 156/ 0.16
East Irish Sea (only 1300 m)	882,836/ 883/ 0.88
Wessex Basin	5,256,120/ 5,256/ 5.3
East Yorks - Boulby Halite	0 (too thin)
East Yorks - Fordon Evaporites	1,663,865/ 1,664/ 1.7
Totals (MWh)	7,958,394
Totals (GWh)	7,958
Totals (TWh)	8

Pumped hydro plant Goldisthal

$P = 1.060 \text{ MW} \blacklozenge W = 8\text{h} \times 1.060 \text{ MW} \blacklozenge \eta > 80\%$

Crotogino
(Seville, 15 June 2010)



19.5

110

657

208

995

• 8 GWh

AND...only one cycle.....

